AquaPro Design Software User Manual

Leadership in Filtration

MANN+HUMMEL

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Warranties, Contractual Obligations or Disclaimers Associated with the Software

The software only projects reverse osmosis and nanofiltration system performance from a user-controlled set of data input and design decisions and does not state whether a system design is realistic or optimized for a given set of conditions.

Solely the user is responsible to review and state the system design based on the anticipated or existing pretreatment, reasonable design guidelines, and experience. Consequently, the information provided by the software is only referred to the user and cannot be used to raise any claim for liability or warranty against MANN+HUMMEL. No guarantee of product or system performance is expressed or implied unless provided in a separate warranty statement signed by an authorized MANN+HUMMEL representative.

The software is intended to be used by persons having the requisite technical skill, at their own discretion and risk. MANN+HUMMEL shall not be liable for any error or miscalculation in results obtained by using the software.

Because use conditions and applicable laws may differ from one location to another and may change with time, solely users are responsible for determining whether products are appropriate for their use.

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List of Illustrations

Introduction

Audience Description

The software is intended to be used by persons having the requisite technical skill, at their own discretion and risk.

Applicability Statement

In water purification applications with a well-pretreated feed, the expected performance of MANN+HUMMEL RO and NF membranes can be reasonably projected using MANN+HUMMEL's AquaPro projection software. However, many situations require various qualification and testing steps prior to the start-up of a full-scale system. Some such situations include variable or difficult feed quality, process applications, large plant sizes, the presence of organics or silica, and unique or novel applications. Small-scale testing to ensure that the desired separation is achievable at appropriate pressures, membrane flux, and recovery rates is critical to verify the sustainability of full-scale operation, minimize risk, and fine-tune appropriate operating conditions.

Pilot testing is the most effective testing method used to assess a membrane's feasibility for a specific feed supply. The goals of piloting can include gathering pretreatment data, determining scaled-up operational characteristics and costs, testing cleaning regimens, ensuring stable operation over time with adequate permeate quality, familiarizing operators with the membrane technology, and demonstrating regulatory compliance. Pilot plants should use at least one 40-inch-long element, and the system configuration should mimic that of the scaled system. Pilot systems should run for a minimum of one month, although longer durations allow for a more accurate study of membrane fouling effects. The permeate flow rate of the pilot should be no less than 1% of the scaled system permeate flow rate.

One of the most important goals of a pilot plant is studying the fouling effects over time and ensuring that an effective and economic cleaning regimen can be implemented to maintain membrane performance. Cleaning cycles, controls, chemical feed equipment, and post treatment, should all be considered. A site-specific understanding of fouling tendencies is especially necessary for complex feed qualities.

Problem Reporting Instructions

- MANN+HUMMEL appreciates feedback. For suggestions to improve or to report problems, please email:

software.wms@mann-hummel.com

Installation

Requirements: PC with Windows 10 and 11.

*Note: This application will not operate on Mac nor mobile or tablet devices.

How to Use AquaPro Design Software

Home

- Define the treatment goal and pick a membrane element
- Define Determine appropriate flux rates from feed water quality
- Use average flux rate to size the system
- Develop a sensible system design
- Project system design to verify that treatment goal is accomplished

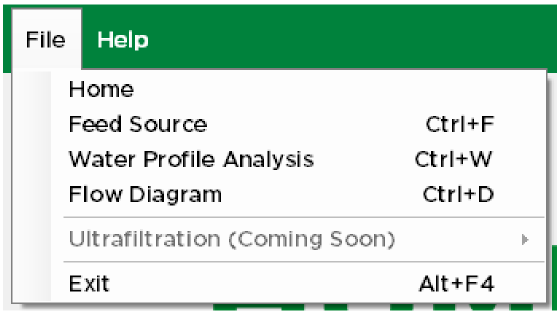


Figure 1: Home

Getting started

1. Navigate to File → Flow Diagram to create a new project OR select from recently opened projects.
2. Select "Units" to choose units of flow, temperature, pressure, and flux
3. Select relevant water type and profile from the drop-down lists
4. Specify pass properties such as membrane age and flux decline
5. Specify required flow rates and recoveries
6. Specify number of stages, passes, vessels, and elements
7. Select element model from drop-down lists
8. Save project, calculate results, and save report

Saving files

Projects are saved as .json files in the local computer. JSON (JavaScript Object Notation) is a file format for data storage and transmission.

Feed source

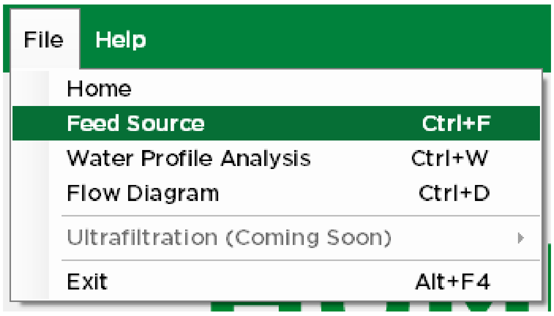
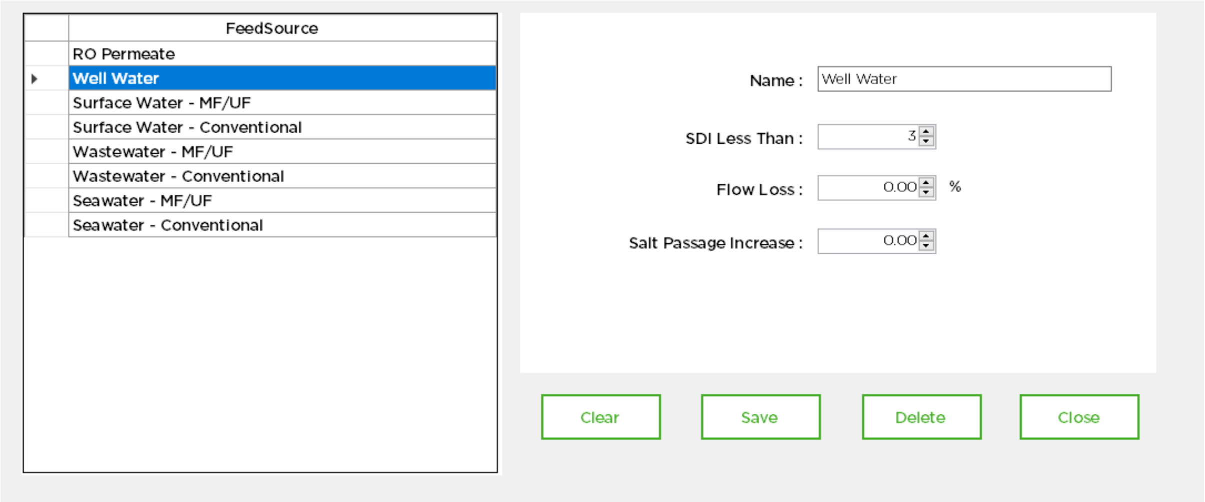


Figure 2: Feed Source



FeedSource
RO Permeate
Well Water
Surface Water - MF/UF
Surface Water - Conventional
Wastewater - MF/UF
Wastewater - Conventional
Seawater - MF/UF
Seawater - Conventional

Name : Well Water

SDI Less Than : 3

Flow Loss : 0.00 %

Salt Passage Increase : 0.00

Figure 3: Feed Source Selection

Water profile analysis

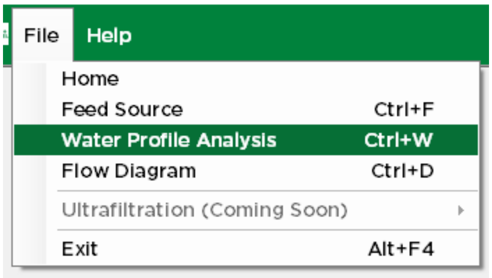
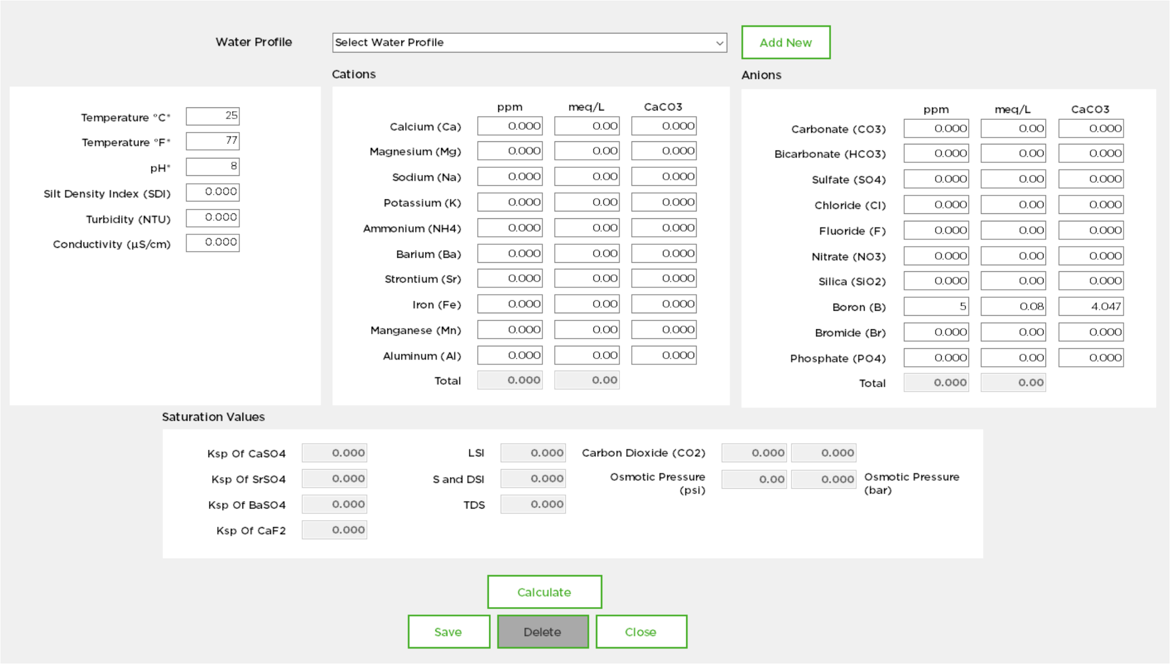


Figure 4: Water Profile Analysis


Water Profile: Select Water Profile

Temperature °C*	25
Temperature °F*	77
pH*	8
Silt Density Index (SDI)	0.000
Turbidity (NTU)	0.000
Conductivity (µS/cm)	0.000

Cations

	ppm	meq/L	CaCO3
Calcium (Ca)	0.000	0.00	0.000
Magnesium (Mg)	0.000	0.00	0.000
Sodium (Na)	0.000	0.00	0.000
Potassium (K)	0.000	0.00	0.000
Ammonium (NH4)	0.000	0.00	0.000
Barium (Ba)	0.000	0.00	0.000
Strontium (Sr)	0.000	0.00	0.000
Iron (Fe)	0.000	0.00	0.000
Manganese (Mn)	0.000	0.00	0.000
Aluminum (Al)	0.000	0.00	0.000
Total	0.000	0.00	

Anions

	ppm	meq/L	CaCO3
Carbonate (CO3)	0.000	0.00	0.000
Bicarbonate (HCO3)	0.000	0.00	0.000
Sulfate (SO4)	0.000	0.00	0.000
Chloride (Cl)	0.000	0.00	0.000
Fluoride (F)	0.000	0.00	0.000
Nitrate (NO3)	0.000	0.00	0.000
Silica (SiO2)	0.000	0.00	0.000
Boron (B)	5	0.08	4.047
Bromide (Br)	0.000	0.00	0.000
Phosphate (PO4)	0.000	0.00	0.000
Total	0.000	0.00	

Saturation Values

Ksp Of CaSO4	0.000	LSI	0.000	Carbon Dioxide (CO2)	0.000 0.000
Ksp Of SrSO4	0.000	S and DSI	0.000	Osmotic Pressure (psi)	0.00
Ksp Of BaSO4	0.000	TDS	0.000	Osmotic Pressure (bar)	0.000
Ksp Of CaF2	0.000				

Figure 5: Water Profile Analysis Selection

Flow diagram

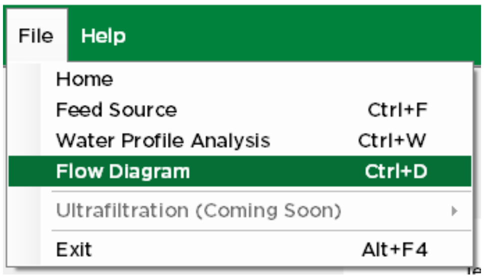
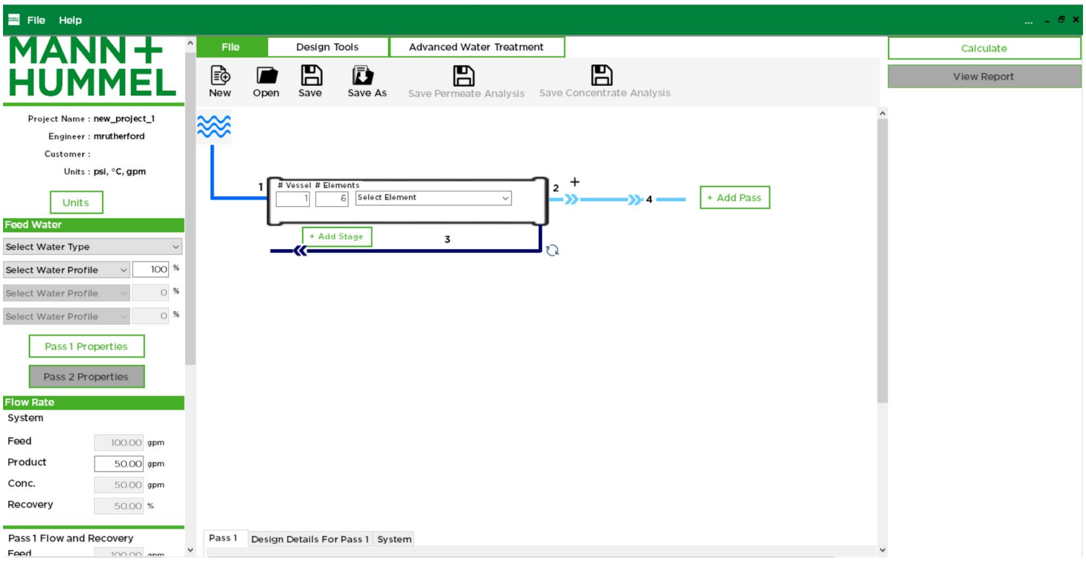


Figure 6: Flow Diagram



Project Name : new_project_1
Engineer : mrutherford
Customer :
Units : psi, °C, gpm

Select Water Type
Select Water Profile 100 %
Select Water Profile 0 %
Select Water Profile 0 %

Vessel 1
Elements 6
Select Element

System

Feed	100.00	gpm
Product	50.00	gpm
Conc.	50.00	gpm
Recovery	50.00	%

Pass 1 Flow and Recovery

Feed	100.00	gpm

Figure 7: Flow Diagram Selection

System parameters

To model the performance of a system, the following operation parameters are helpful to have:

1. Feed pressure
2. Permeate pressure
3. Concentrate pressure
4. Feed water analysis*
5. Permeate water analysis*
6. Feed flow
7. Permeate flow
8. Concentrate flow
9. Recycle flow
10. Operating temperature

*Feed and permeate water analyses will provide accurate solute concentrations. Frequently, feed and permeate conductivity readings are used to estimate the TDS (total number of inorganic salts) entering and exiting the system.

Two-stage system

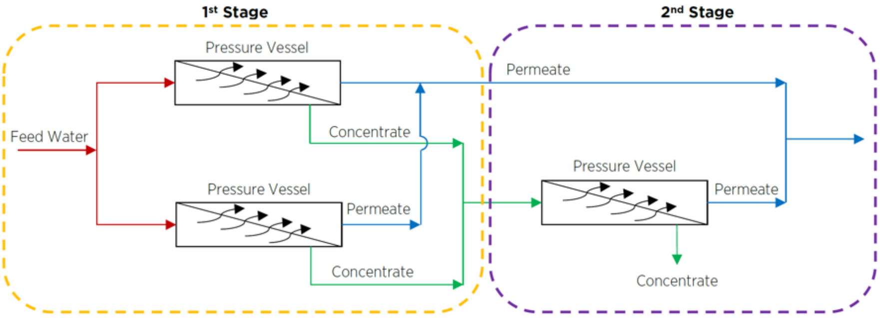


Figure 8: Two-stage System

A two-stage system; the concentrate from the first stage becomes the feed to the second stage.

Two-pass RO

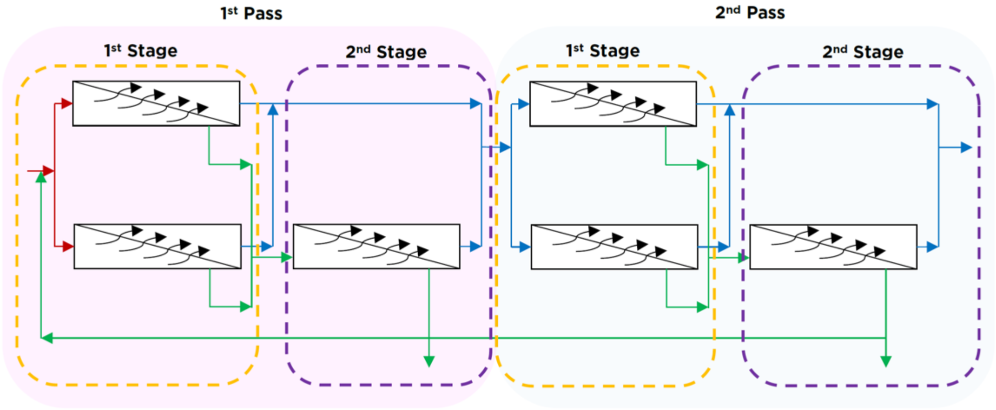


Figure 9: Two-pass RO

A two-pass system; the permeate from the first pass becomes the feed to the second pass.

DESIGN RECOMMENDATIONS FOR RO AND NF ELEMENTS.

Feed Source	RO Permeate	Well Water	Softened Municipal	Surface	Wastewater (filtered tertiary effluent)
Feed Silt Density Index (SDI)	< 1	< 3	< 3	< 5	< 3
Typical Target Flux Lmh (gfd)	37 (22)	26 - 31 (15 - 18)	27 - 31 (16 - 18)	20 - 24 (12 - 14)	17 - 22 (10 - 13)
Maximum Element Recovery %	30	19	17	15	14

RECOMMENDED FLOW RATES PER PRESSURE VESSEL FOR 4”, 8”, AND 8.5” ELEMENTS.

Model	Minimum Concentrate m^3/h (gpm)	Maximum Feed m^3/h (gpm)
4”	1.1 (50)	4.5 (20.0)
8”	4.5 (20.0)	18.2 (80.0)
8.5”	4.5 (20.0)	19.3 (85.0)

- For cleaner streams, systems may be successfully operated at lower concentrate flow. For streams that are more prone to fouling or scaling, systems may be successfully operated at higher concentrate flow.

Design Tools

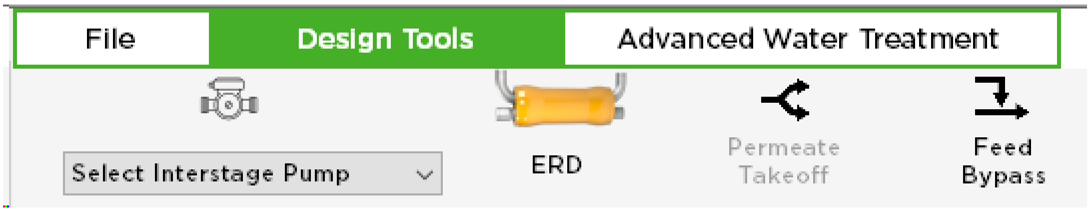
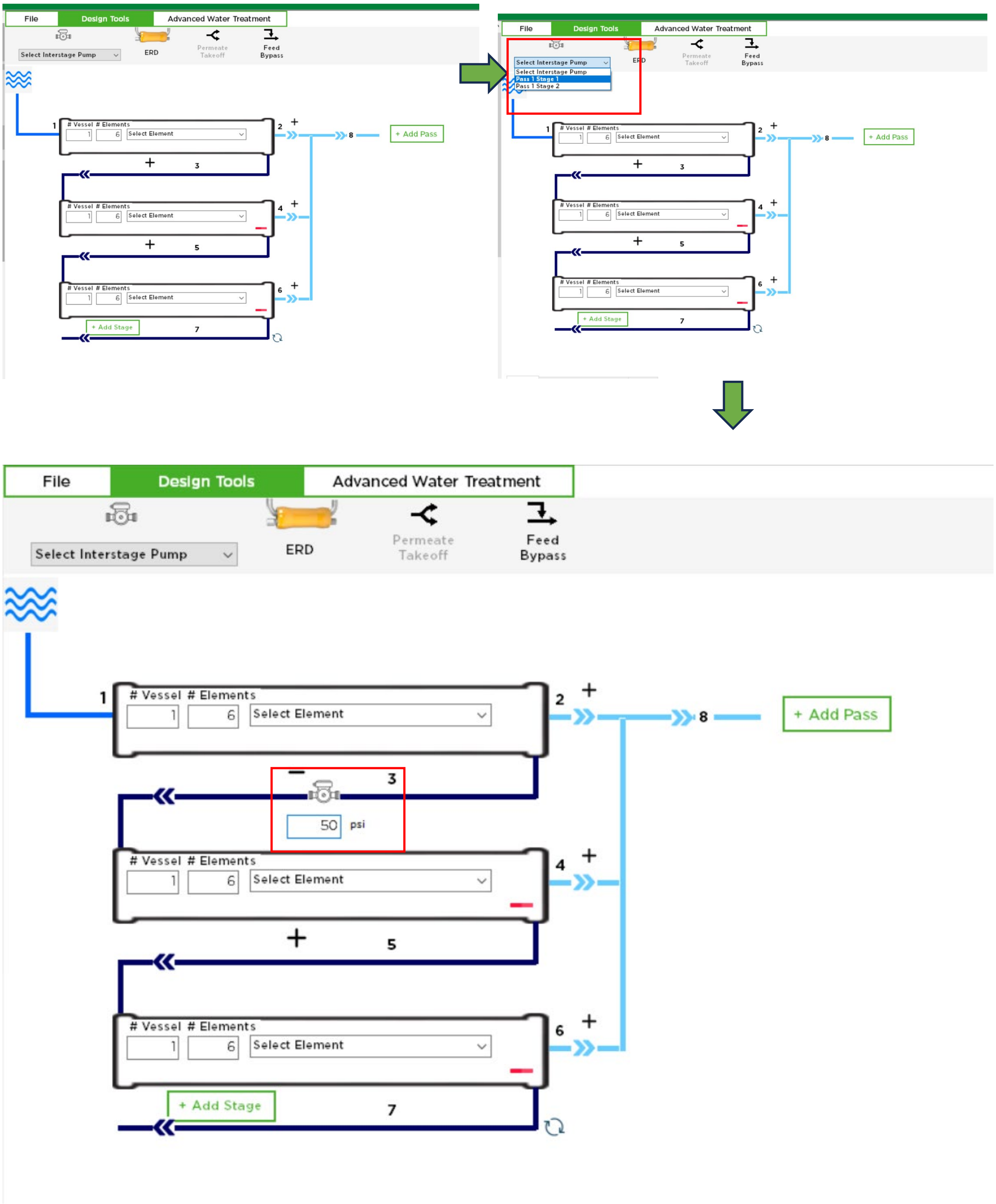


Figure 10: Available Design Tools in Flow Diagram

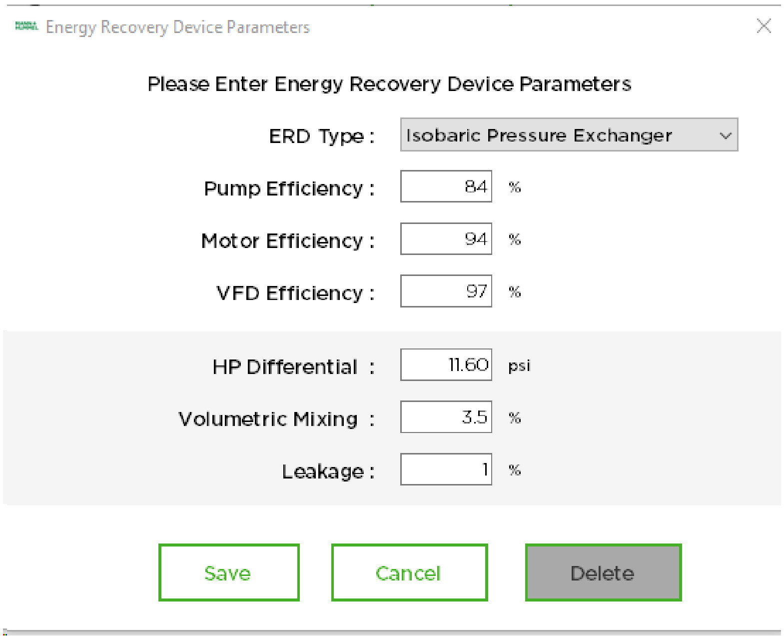
The following are available from the “Design Tools” selection in the Flow Diagram:

- Interstage Pump
- Energy Recovery Device (ERD)
- Permeate Takeoff
- Feed Bypass

Interstage booster pump



Energy recovery device



Please Enter Energy Recovery Device Parameters

ERD Type : Isobaric Pressure Exchanger

Pump Efficiency : 84 %

Motor Efficiency : 94 %

VFD Efficiency : 97 %

HP Differential : 11.60 psi

Volumetric Mixing : 3.5 %

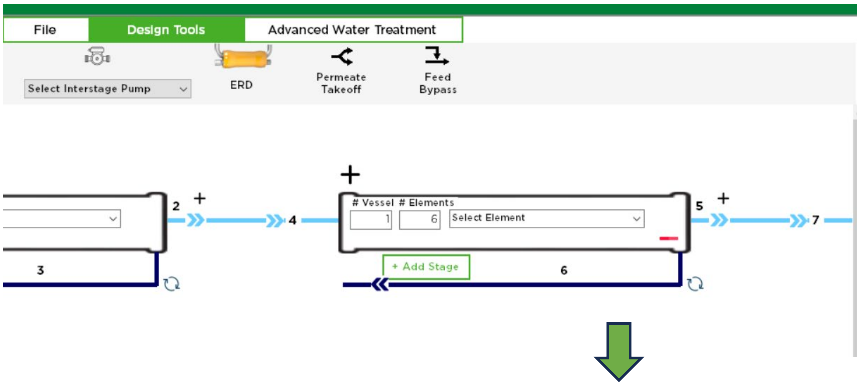
Leakage : 1 %

Figure 11: Standard Energy Recovery Device Parameters

Permeate takeoff

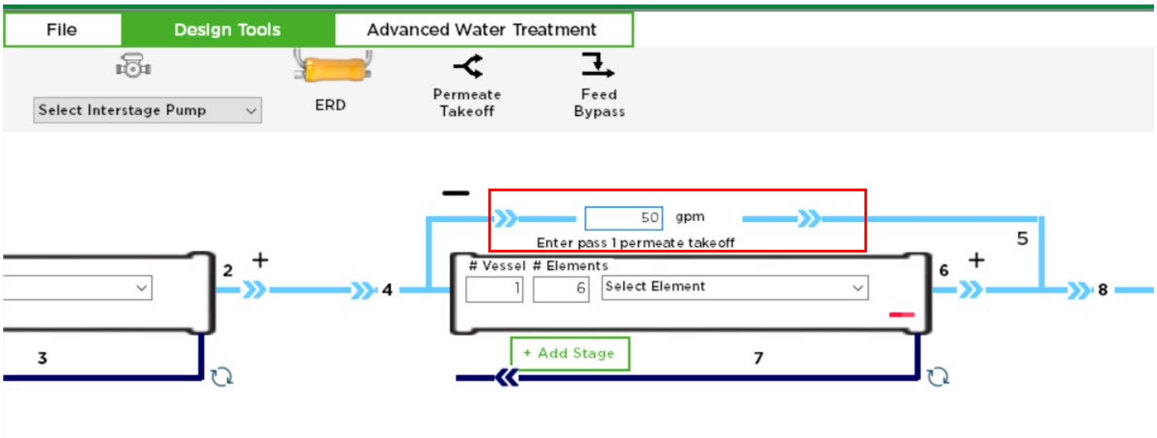
Figure 12: Permeate Takeoff

Permeate takeoff is available with 2-Pass designs as shown below:



Select Interstage Pump

\# Vessel 1 # Elements 6 Select Element



50 gpm

Enter pass 1 permeate takeoff

Vessel 1 # Elements 6

Figure 13: Example of Permeate Takeoff

Feed bypass

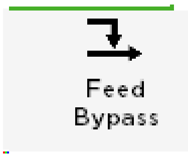
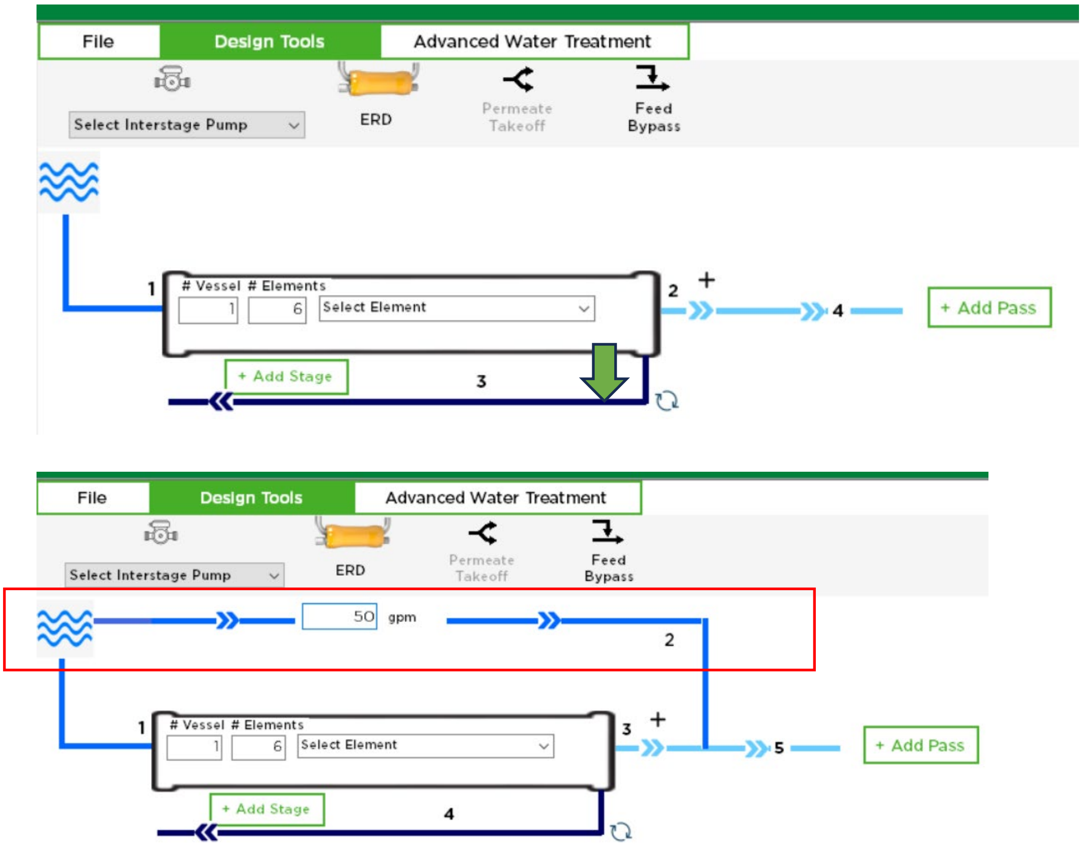


Figure 14: Feed Bypass

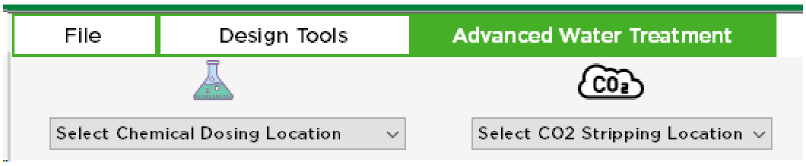


Vessel 1 # Elements 6

50 gpm

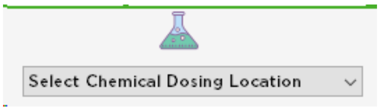
Figure 15: Example of Feed Bypass

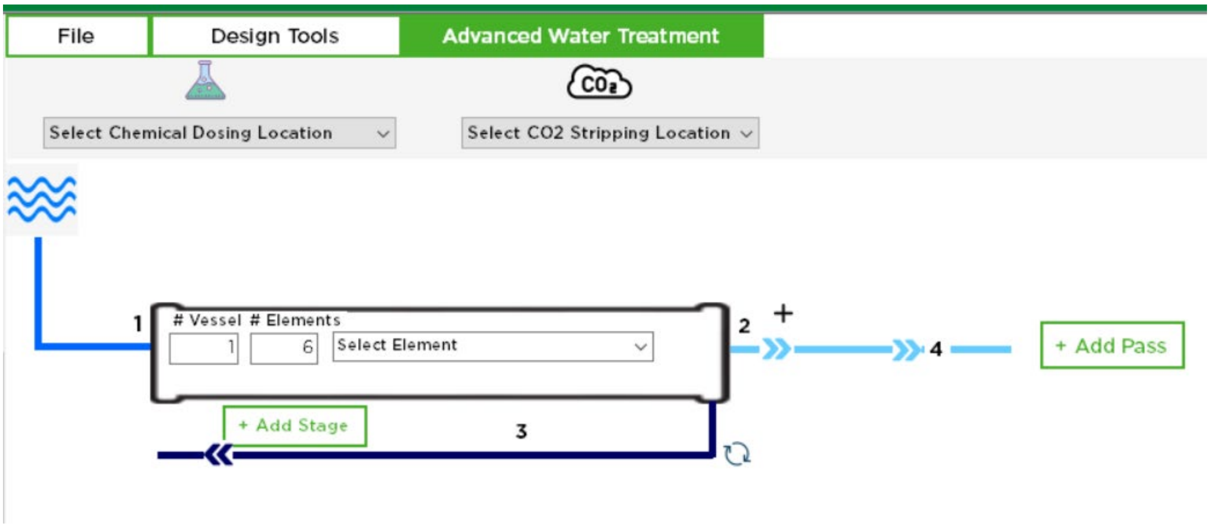
Advance Water Treatment

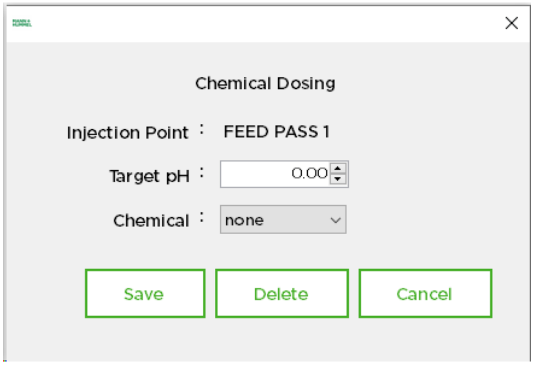


- Chemical Dosing
- CO_2 Stripping

Chemical dosing



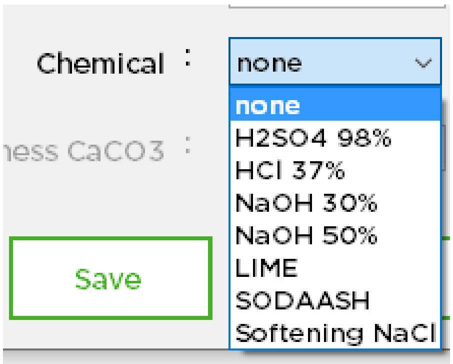



Chemical Dosing

Injection Point : FEED PASS 1

Target pH : 0.00

Chemical : none


Chemical : none

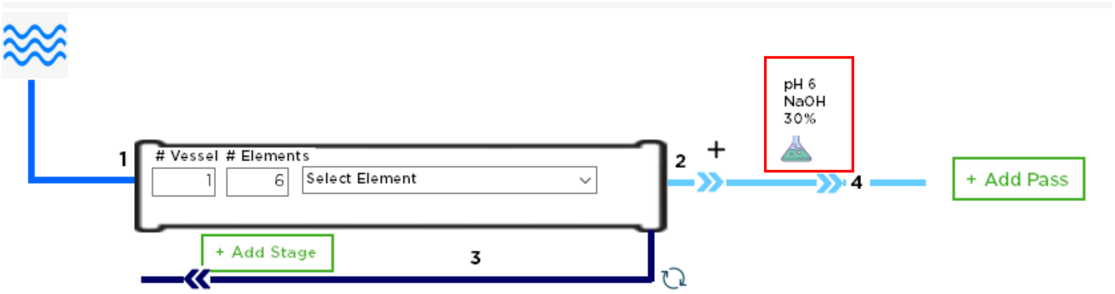
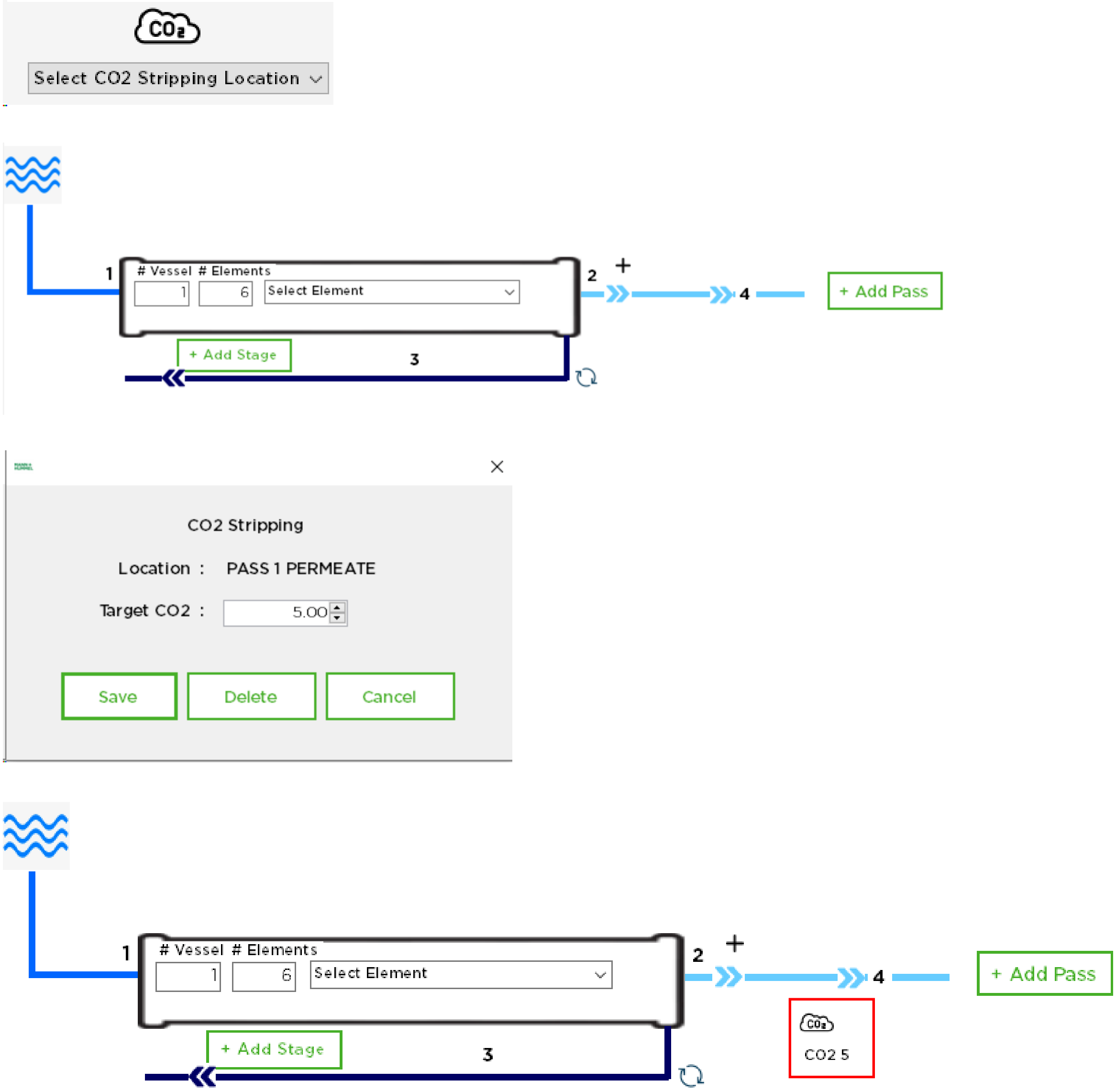


Figure 16: Example of Chemical Dosing

CO_2 stripping



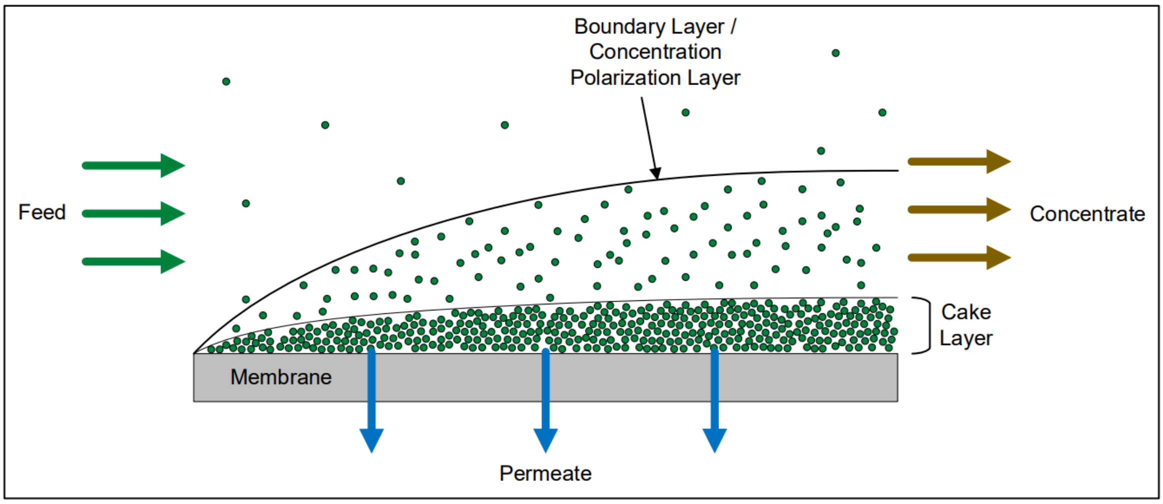
CO2 Stripping

Location : PASS 1 PERMEATE

Target CO2 : 5.00

Figure 17: Example of CO_2 Stripping

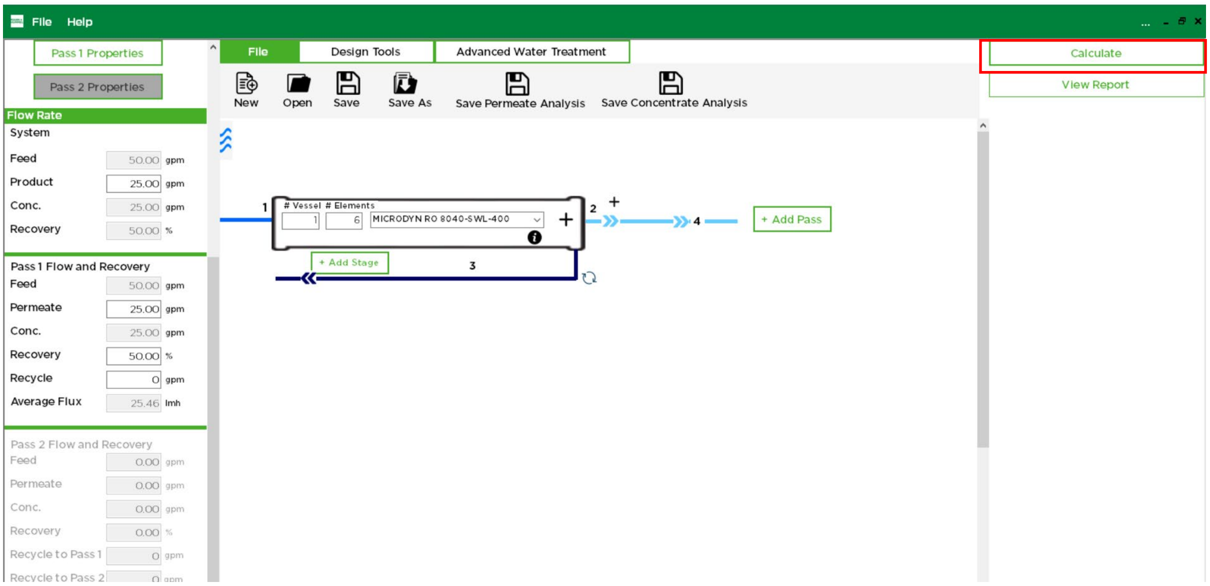
Concentration polarization: beta



The concentration of solute near the membrane surface is greater than that of the bulk feed solution.

The beta value is a measure of the concentration polarization at the membrane surface. Normal engineering practice is to maintain a beta value of less than 1.2. This value would indicate a concentration at the membrane surface 20% higher than in the bulk solution.

Calculate



Flow Rate

System

Feed 50.00 gpm

Product 25.00 gpm

Conc. 25.00 gpm

Recovery 50.00 %

Pass 1 Flow and Recovery

Feed 50.00 gpm

Permeate 25.00 gpm

Conc. 25.00 gpm

Recovery 50.00 %

Recycle 0 gpm

Average Flux 25.46 lmh

Pass 2 Flow and Recovery

Feed 0.00 gpm

Permeate 0.00 gpm

Conc. 0.00 gpm

Recovery 0.00 %

Recycle to Pass 1 0 gpm

Recycle to Pass 2 0 gpm

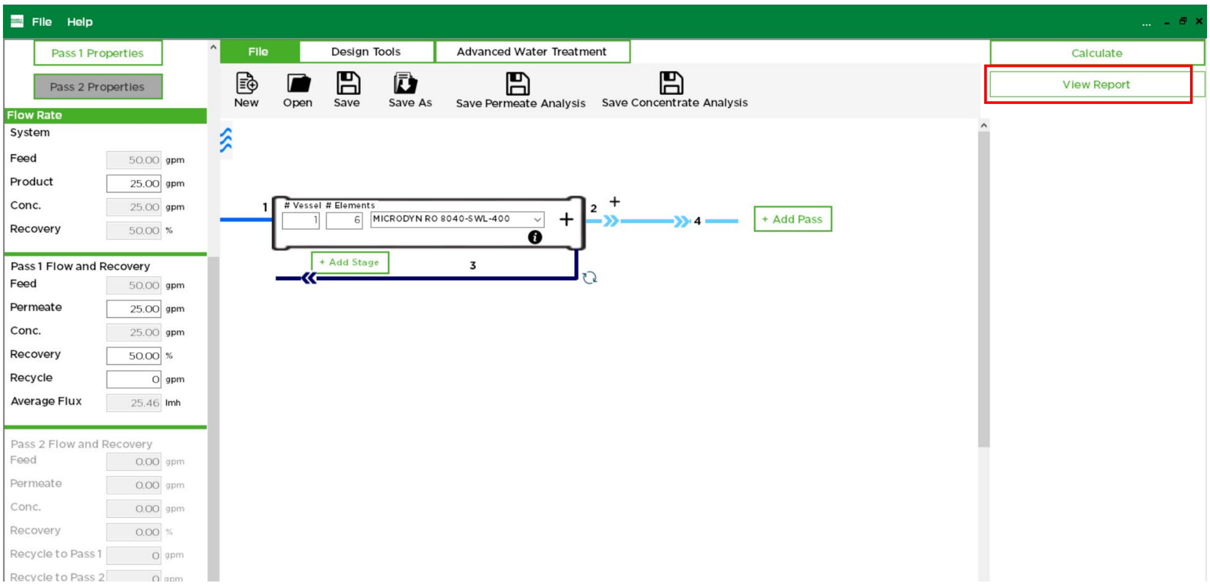
Vessel 1 # Elements 6 MICRODYN RO 8040-SWL-400

Figure 18: Example of Calculation Selection for the Flow Diagram

Warnings will be displayed in the right side of the Flow Diagram.

View report

Once ready to generate the projection report, please select "View Report".



Flow Rate

System

Feed 50.00 gpm

Product 25.00 gpm

Conc. 25.00 gpm

Recovery 50.00 %

Pass 1 Flow and Recovery

Feed 50.00 gpm

Permeate 25.00 gpm

Conc. 25.00 gpm

Recovery 50.00 %

Recycle 0 gpm

Average Flux 25.46 lmh

Pass 2 Flow and Recovery

Feed 0.00 gpm

Permeate 0.00 gpm

Conc. 0.00 gpm

Recovery 0.00 %

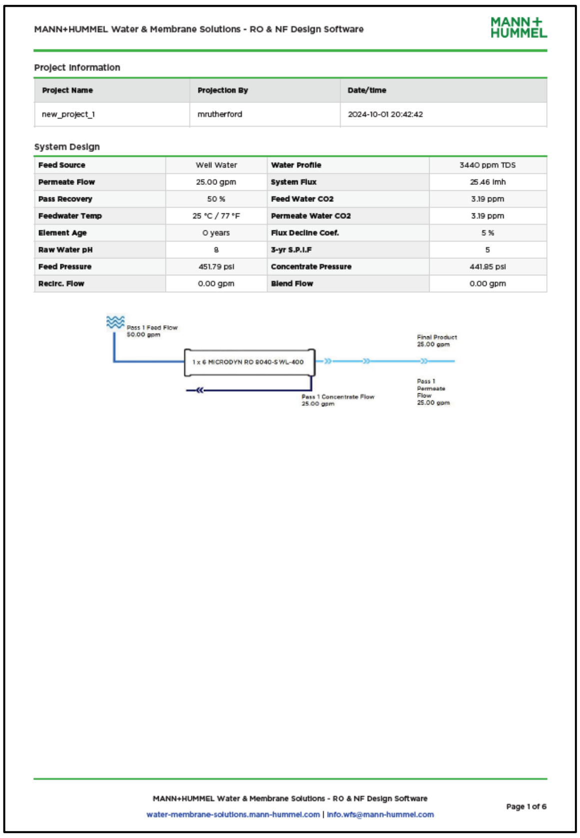
Recycle to Pass 1 0 gpm

Recycle to Pass 2 0 gpm

Vessel 1 # Elements 6 MICRODYN RO 8040-SWL-400

Figure 19: Example of View Report Selection from the Flow Diagram

A PDF file will be generated, and the user can save and/or print the report. An example is shown below:



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Project Information

Project Name	Projection By	Date/time
new_project_1	mrutherford	2024-10-01 20:42:42

System Design

Feed Source	Well Water	**Water Profile**	3440 ppm TDS
Permeate Flow	25.00 gpm	**System Flux**	25.46 lmh
Pass Recovery	50 %	**Feed Water CO2**	3.19 ppm
Feedwater Temp	25 °C / 77 °F	**Permeate Water CO2**	3.19 ppm
Element Age	0 years	**Flux Decline Coef.**	5 %
Raw Water pH	8	**3-yr S.P.I.F**	5
Feed Pressure	451.79 psi	**Concentrate Pressure**	441.85 psi
Recirc. Flow	0.00 gpm	**Blend Flow**	0.00 gpm

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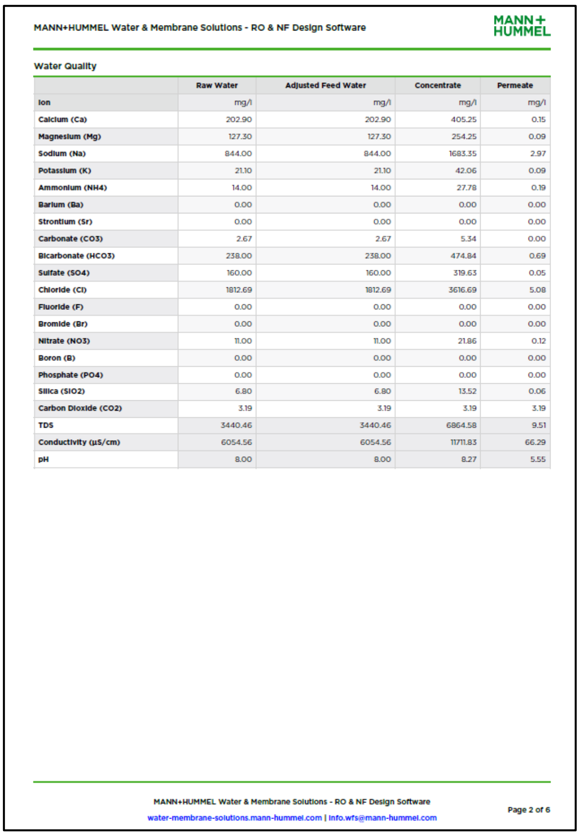

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Water Quality

	Raw Water	Adjusted Feed Water	Concentrate	Permeate
Ion	mg/l	mg/l	mg/l	mg/l
Calcium (Ca)	202.90	202.90	405.25	0.15
Magnesium (Mg)	127.30	127.30	254.25	0.09
Sodium (Na)	844.00	844.00	1683.35	2.97
Potassium (K)	21.10	21.10	42.06	0.09
Ammonium (NH4)	14.00	14.00	27.78	0.19
Barium (Ba)	0.00	0.00	0.00	0.00
Strontium (Sr)	0.00	0.00	0.00	0.00
Carbonate (CO3)	2.67	2.67	5.34	0.00
Bicarbonate (HCO3)	238.00	238.00	474.84	0.69
Sulfate (SO4)	160.00	160.00	319.63	0.05
Chloride (Cl)	1812.69	1812.69	3616.69	5.08
Fluoride (F)	0.00	0.00	0.00	0.00
Bromide (Br)	0.00	0.00	0.00	0.00
Nitrate (NO3)	11.00	11.00	21.86	0.12
Boron (B)	0.00	0.00	0.00	0.00
Phosphate (PO4)	0.00	0.00	0.00	0.00
Silica (SiO2)	6.80	6.80	13.52	0.06
Carbon Dioxide (CO2)	3.19	3.19	3.19	3.19
TDS	3440.46	3440.46	6864.58	9.51
Conductivity (µS/cm)	6054.56	6054.56	11711.83	66.29
pH	8.00	8.00	8.27	5.55

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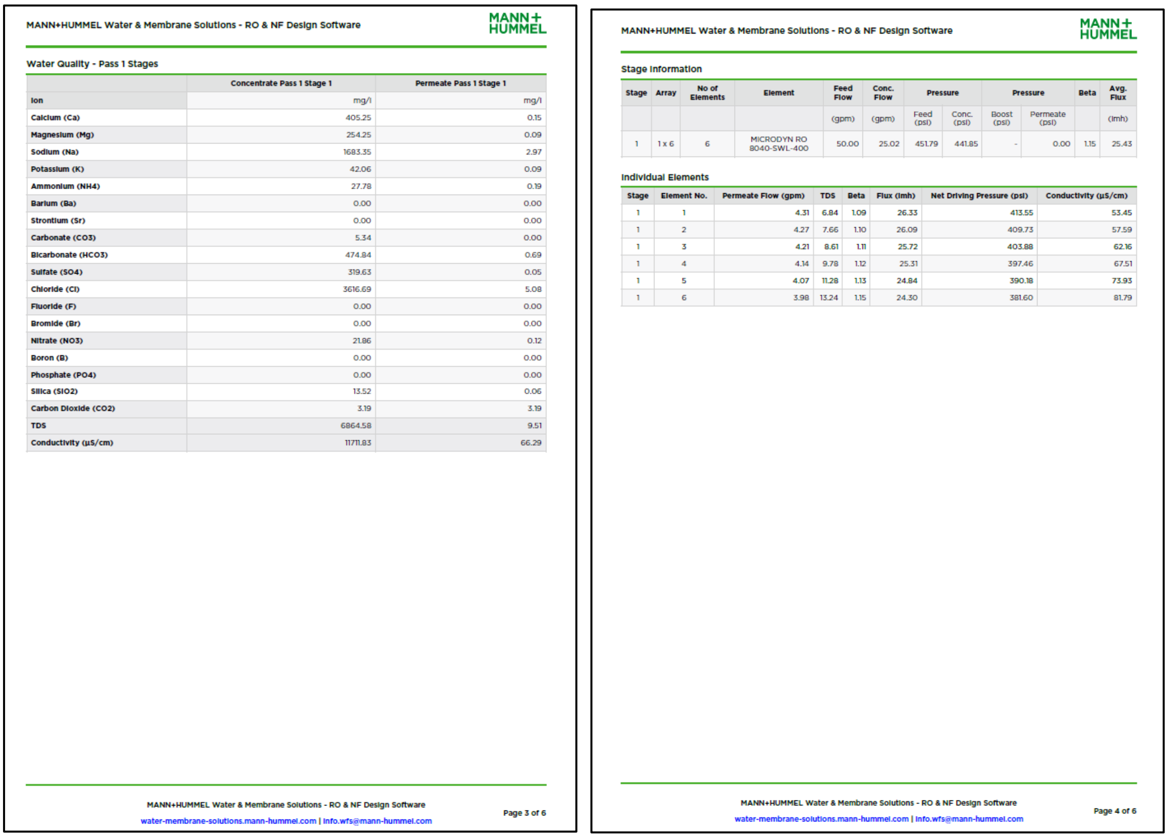

MANN+HUMMEL Water & Membrane Solutions - RO & NF Design Software

Water Quality - Pass 1 Stages

	Concentrate Pass 1 Stage 1	Permeate Pass 1 Stage 1
Ion	mg/l	mg/l
Calcium (Ca)	405.25	0.15
Magnesium (Mg)	254.25	0.09
Sodium (Na)	1683.35	2.97
Potassium (K)	42.06	0.09
Ammonium (NH4)	27.78	0.19
Barium (Ba)	0.00	0.00
Strontium (Sr)	0.00	0.00
Carbonate (CO3)	5.34	0.00
Bicarbonate (HCO3)	474.84	0.69
Sulfate (SO4)	319.63	0.05
Chloride (Cl)	3616.69	5.08
Fluoride (F)	0.00	0.00
Bromide (Br)	0.00	0.00
Nitrate (NO3)	21.86	0.12
Boron (B)	0.00	0.00
Phosphate (PO4)	0.00	0.00
Silica (SiO2)	13.52	0.06
Carbon Dioxide (CO2)	3.19	3.19
TDS	6864.58	9.51
Conductivity (µS/cm)	11711.83	66.29

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Stage Information

Stage	Array	No of Elements	Element	Feed Flow	Conc. Flow	Pressure		Pressure		Beta	Avg. Flux
				(gpm)	(gpm)	Feed (psi)	Conc. (psi)	Boost (psi)	Permeate (psi)		(lmh)
1	1 x 6	6	MICRODYN RO 8040-SWL-400	50.00	25.02	451.79	441.85	-	0.00	1.15	25.43

Individual Elements

Stage	Element No.	Permeate Flow (gpm)	TDS	Beta	Flux (lmh)	Net Driving Pressure (psi)	Conductivity (µS/cm)
1	1	4.31	6.84	1.09	26.33	413.55	53.45
1	2	4.27	7.66	1.10	26.09	409.73	57.59
1	3	4.21	8.61	1.11	25.72	403.88	62.16
1	4	4.14	9.78	1.12	25.31	397.46	67.51
1	5	4.07	11.28	1.13	24.84	390.18	73.93
1	6	3.98	13.24	1.15	24.30	381.60	81.79

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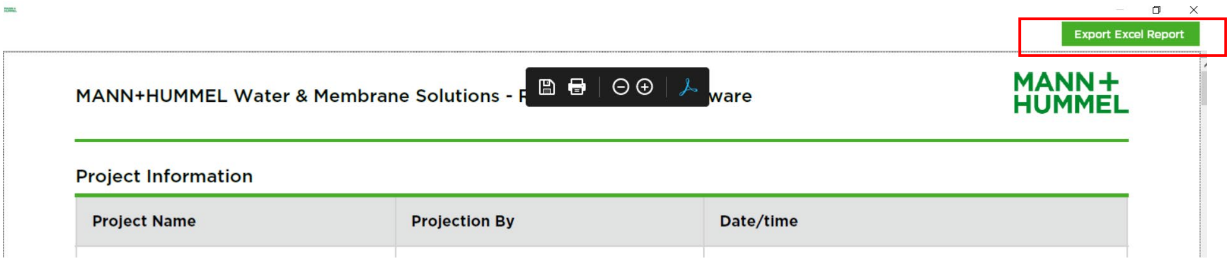
Figure 20: Example Design Projection PDF Report

An Excel report may be generated after the “View Report” button is selected:



MANN+HUMMEL Water & Membrane Solutions - R ware

Project Information

Project Name	Projection By	Date/time

Glossary

Alkalinity

Alkalinity consists of anions (specifically carbonate, bicarbonate and hydroxide ions) that remove hydrogen ions from solution causing the water to have a higher pH. Alkalinity can be reported as M-Alkalinity and P-Alkalinity. M-Alkalinity (also known as Total Alkalinity) measures the amount of carbonate, bicarbonate and hydroxide present. The M-Alkalinity measurement is based on a sulfuric acid titration using a Methyl orange indicator that goes from yellow at a pH of 4.5 to orange at pH of 4.4 at the end point. P-Alkalinity measures the amount of carbonate and hydroxide alkalinity present. The P-Alkalinity measurement is based on a sulfuric acid titration using a Phenolphthalein indicator that goes from pink at a pH of 8.3 to colorless at pH of 8.2 at the endpoint.

Aluminum (Al^{3+})

Due to its valence charge of +3 and relatively small size (which results in aluminum metal ions having a particularly high charge density), aluminum is very reactive. Aluminum will combine with oxygen to form an insoluble oxide. It also tends to complex with negatively charged organic colloids and will readily precipitate when silica is present. Because of this, it is recommended to limit the amount of aluminium in contact with the membranes to 0.05 mg/L (maximum).

Ammonia (NH_3)

Ammonia is a dissolved gas and will not be rejected by an RO or NF membrane. However, ammonia is in equilibrium with the ammonium cation (NH_{4+}). As long as the temperature and pH are less than 40°C (104°F) and 7 respectively, more than 95% will be present as NH_{4+} and the rejection should be better than 98%. However, if both the temperature and pH are allowed to increase, the amount of ammonia will increase, and rejection will decrease.

Ammonium (NH_4^+)

Ammonium is a monovalent cation (i.e. it has a valence charge of +1). Ammonium salts are very soluble and generally do not cause scaling problems.

Array

In a system, an array describes the physical arrangement of the pressure vessels in a multi-stage system. In a multi-stage system, each stage can have a determined amount of pressure vessels (which typically house 6 elements each). The reject of each stage then becomes the feed stream for the next successive stage. For example, the two-stage system displayed above is a 2:1 array, meaning that the concentrate (or reject) of the first two vessels is fed to the next single vessel.

Barium (Ba^{2+})

Barium is a divalent cation (i.e. it has a valence charge of +2). When in the presence of sulfates, barium sulfate ($BaSO_4$) easily falls out of solution due to its low solubility and may lead to a scaling problem. Barium sulfate solubility is lower with increasing sulfate levels and decreasing temperatures.

Barium sulfate scale is extremely difficult to redissolve; barium is generally controlled with antiscalants.

Bicarbonate (HCO_3^-)

Bicarbonate is a monovalent anion (i.e. it has a valence charge of -1). The solubility of calcium bicarbonate is low and can cause a scaling problem. Calcium bicarbonate solubility is measured using LSI (Langelier Saturation Index) for brackish waters or the Stiff- Davis Index for seawaters and is lower with increasing temperature and pH. Bicarbonate is one component of alkalinity. Its concentration is in a balance with carbon dioxide between the pH range of 4.4 and 8.2 and in a balance with carbonate between the pH range of 8.2 and 9.6.

BOD (Biological Oxygen Demand)

BOD is a non-specific test that measures the quantity of biologically degradable organic matter in the water source. The test measures the quantity of oxygen depletion resulting from the ability of common bacteria to digest organic matter during a five-day incubation period at 20°C (68°F). As a rough rule of thumb, it is recommended to keep BOD levels below 5 ppm using pretreatment (typically some sort of filtration) to prevent organic fouling in natural water sources.

Boron (B)

Unlike most of the other elements in water, boron is not ionized (has no charge). Boron takes two forms in water: boric acid, $B(OH)_3$, or borate ion, $B(OH)_4^-$. The relative concentrations of boric acid and borate ion are dependent on pH, temperature and salinity. Boric acid becomes more prevalent at $pH < 8$, whereas the borate ion will become dominant at $pH > 10$. Because RO and NF membranes are much better at removing charged ions, the removal of borate ion is easier than the removal of boric acid.

Brackish Water

Brackish water can be defined as feed water with low to medium TDS (Total Dissolved Solids) levels (up to 15,000 ppm) that can be treated with a brackish water RO element designed for 41.4 bar (600 psi) maximum feed pressure (high pressure elements also available).

Calcium (Ca^{2+})

Calcium is a divalent cation. Calcium, along with magnesium, is a major component of hardness in brackish water. Hardness can fall out of solution, leaving behind scale formation. The solubility of calcium sulfate, $CaSO_4$, is typically limited to an LSI (Langelier Saturation Index) value of positive 1.8 to 2.5 when using an antiscalant; and LSI of < 0 is recommended when no antiscalant is employed. Additionally, the positive charge characteristics of calcium may cause it to bind up with phosphate ions, which are strongly anionic.

Carbon Dioxide (CO_2)

Carbon dioxide is a gas that when dissolved in water reacts with the water to form weak carbonic acid, H_2CO_3. The concentration of carbon dioxide in water is typically indirectly determined by graphical comparison to the bicarbonate concentration and pH. Carbon dioxide and the bicarbonate ion are in equilibrium between the pH range of 4.4 and 8.2. At pH 4.4, the equilibrium reaction favors carbon dioxide, whereas at pH 8.2, the reaction favors bicarbonate. Carbon dioxide levels are calculated based on the bicarbonate levels and pH of the water. Carbon dioxide, being a gas, is not rejected or concentrated by a RO membrane, therefore its concentration will be the same in the feed, permeate and concentrate.

Carbonate (CO_3^{2-})

Carbonate is a divalent anion. The solubility of calcium carbonate is low and may cause a scaling problem. Calcium carbonate solubility is measured using LSI (Langelier Saturation Index) for brackish waters or SDSI (Stiff-Davis index) for seawaters. Calcium carbonate is unusual in that its solubility lowers with increasing temperature and increasing pH. Carbonate is one component of alkalinity, and its concentration is in equilibrium with bicarbonate between the pH range of 8.2 and 9.6. At a pH of 9.6 and higher, all alkalinity is in carbonate form.

Chloride (Cl^-)

Chloride is a monovalent anion. Nearly all chloride salts are soluble in water and pose little threat to a membrane system. However, if the system concentrate is heavily concentrated with chloride, a higher-grade stainless steel may be required for the high-pressure piping (or housings if stainless steel) to prevent corrosion. Chloride is also the anion used to automatically balance a feed water analysis.

COD (Chemical Oxygen Demand)

COD is a non-specific test that measures the quantity of both biodegradable and non-biodegradable organic matter. The test measures the ability of a hot chromic acid solution to oxidize organic matter. As a rough rule of thumb, it is recommended to keep COD levels below 8 ppm to prevent organic fouling in natural water sources.

Color & True Color

Color is a non-specific test that measures the relative level of organic compounds in water based on their contribution to adding color and is reported in APHA units relative to the platinum standard. True color is the color that remains after the sample is filtered through a 0.45-micron filter. True color can irreversibly adsorb to the membrane, resulting in permanent flux loss. For that reason, true color should be less than 3 APHA units in RO feed water.

Conductivity

Conductivity is a measurement of the ability of water to transmit electricity due to the presence of dissolved ions. Conductivity is measured by a conductivity meter and is reported as micromhos/cm or micro-Siemens/cm. Conductivity is a convenient method of determining the level of ions in a water but is non-specific in what the ions are. Absolute pure water with no ions will not conduct an electrical current.

Copper (Cu^{2+})

Copper is usually not present in natural water sources, but it is possible to pick up trace concentrations from piping materials. Copper tends to fall out of solution with increasing pH. As a transition metal, copper may increase the oxidation potential of oxidizing agents.

Fluoride (F^-)

Fluoride is a monovalent anion. Fluoride concentrations are usually low in most water sources. Calcium fluoride is fairly insoluble. Antiscalants do not generally do a good job at inhibiting formation of calcium fluoride, so acid feed is typically recommended to minimize formation of this scale on RO membranes.

Flux

The ratio between permeate flow rate and total active membrane area.

Free Chlorine

Under certain conditions, the presence of chlorine and other oxidizing agents will cause premature membrane failure. It is highly recommended to removal residual free chlorine by pretreatment prior to membrane exposure.

*Note: Cellulose acetate membranes are able to tolerate a small amount of free chlorine in the feed water whereas thin-film composite membranes cannot.

Hardness

Calcium and magnesium make up the vast majority of what is called water hardness. Hardness can fall out of solution, leaving behind scale formation. The positive charge characteristics of hardness can also cause it to bind up with phosphate ions (which are strongly anionic). Calcium phosphate scale is also not inhibited well by antiscalants, so removal of calcium hardness or acid feed is recommended to control formation of this scale.

Hydroxide (OH^-)

Alkalinity consists of anions that remove hydrogen ions from solution and causing the water to have a higher pH. These anions include carbonate, bicarbonate and hydroxide.

Iron (Fe^{2+} or Fe^{3+})

Iron is a water contaminant that takes two major forms. The water-soluble form, known as its divalent ferrous state (Fe_{2+}) is a by softeners or its precipitation can be controlled by the use of a dispersant chemical in the feed water (note that ferrous iron concentrations of over 1 ppm can foul softener resin). The water-insoluble form, known as its ferric state (Fe_{3+}) has a +3 valence charge. Typically, membrane manufacturers will recommend that combined iron levels be less than 0.05 ppm in the feed. If all iron is in the soluble ferrous state, iron levels up to 0.5 ppm in the feed can be tolerated if the pH is less than 7.0 (though an iron dispersant is recommended). The introduction of air into water with soluble ferrous will result in the oxidation to insoluble ferric iron. Soluble iron can be treated with dispersants or can be removed by iron filters, softeners or lime softening. Insoluble ferric iron oxides or ferric hydroxides, being colloidal in nature, will foul the front end of a system. It can also catalyze the oxidative effects of residual oxidizing agents which may lead to membrane degradation. Insoluble iron can be removed by various pretreatment methods, but precautions must be taken to prevent membrane damage.

LSI (Langelier Saturation Index)

LSI is a method of reporting the scaling or corrosive potential of low TDS brackish water based on the level of saturation of calcium carbonate. LSI is important in determining whether a water is corrosive (has a negative LSI) or will tend to scale calcium carbonate (has a positive LSI). The LSI value is calculated by subtracting the calculated pH of saturation of calcium carbonate from the actual feed pH. Calcium carbonate solubility decreases with increasing temperature, higher pH, higher calcium concentration and higher alkalinity levels. The LSI value can be lowered by reducing pH by the injection of an acid (typically sulfuric or hydrochloric) into the RO feed water. A recommended target LSI in the RO concentrate is -0.2 without use of antiscalant (which indicates that the concentrate is a pH of 0.2 below the point of calcium carbonate saturation) which allows for pH excursions in actual plant operation. The use of an antiscalant allows for a concentrate LSI of up to 2.5.

Magnesium (Mg^{2+})

Magnesium is a divalent cation and accounts for about a third of the hardness in brackish water but can have a concentration five times higher than calcium in sea water. Hardness can fall out of solution, leaving behind scale formation. The positive charge characteristics of hardness can also cause it to bind up with phosphate ions which are strongly anionic.

Manganese (Mn^{2+})

Manganese is a divalent cation and a water contaminant present in both well and surface waters, with levels up to 3 ppm. Manganese, like iron, can be found in organic complexes in surface waters. In oxygen-free water, it is soluble. In the oxidized state, it is insoluble and usually in the form of black manganese dioxide (MnO_2) precipitate. If the manganese concentration is greater than 0.05 mg/L, means for removal should be heavily considered to prevent fouling and possible membrane degradation. Dispersants used to control iron fouling can be used to help control manganese fouling.

Nanofiltration

Similar to RO, NF is a pressure-driven membrane filtration process that utilizes a semi-permeable membrane and crossflow filtration to separate a feed into a purified permeate stream and a concentrate stream containing a high percentage of the impurities found in the raw water.

NF requires lower operating pressures than RO and has a slightly more open structure allowing predominantly monovalent ions to pass through the membrane, while largely rejecting divalent ions. This has been especially relevant in the application of water softening where NF membrane technology is used to reduce hardness (calcium and magnesium) and remove organics, color, bacteria, THM (trihalomethane) precursors and other impurities from the raw water supply. This has also been especially relevant in process applications including divalent ion concentration, dextrose purification, food and dairy applications where piperazine NF membranes are typically used to pass 50 to 90% monovalent ions while still rejecting the majority of divalent ions.

Although RO is necessary for seawater desalination and brackish water treatment containing very high levels of dissolved solids (TDS), many water supplies do not require the almost total salt removal provided by RO. NF membranes partially demineralize water, removing between 10 to 90% of dissolved salts compared to >99% for RO.

Nitrate (NO_3^-)

Nitrate is a monovalent anion. Nitrate salts are highly soluble and generally do not cause a scaling problem. It is desirable to maintain a nitrate concentration below 40 mg/L in drinking water. Because nitrates are weakly charged, they typically exhibit higher passage rates compared to other monovalent ions such as chloride.

NOM (Natural Organic Matter)

NOM is the organic material in surface or ground water and typically consists of negatively charged colloids or suspended solids comprised of tannins or lignins (water soluble humic acid compounds resulting from the decay of certain vegetative matter). Naturally occurring organic material can be a foulant to RO and NF membranes, particularly to negatively charged polyamide thin-film composite membranes. Neutrally charged RO and NF membranes (i.e. neutrally charged thin-film and cellulose acetate) are more resistant to organic fouling. A RO and NF membrane will reject organic compounds and generally, organic compounds with a molecular weight greater than 200 are rejected at levels greater than 99%. The rejection of compounds with molecular weights less than 200 will vary based on molecular weight, shape and ionic charge.

Oil & Grease

Oil & Grease can easily foul an RO or NF membrane. It is therefore highly recommended to completely remove oil and grease prior to the membrane via pretreatment. Effective pretreatment will target complete removal of oil & grease to prevent membrane fouling.

pH

The pH of the feed water measures the concentration of hydrogen ions which determines whether the water is acidic or basic. A pH of 7.0 is considered neutral. A pH between 0.0 and 7.0 is acidic, while a pH between 7.0 and 14.0 is basic. pH is important in defining the alkalinity equilibrium levels of carbon dioxide, bicarbonate, carbonate and hydroxide ions. The concentrate pH is typically higher than the feed due to the higher concentration of bicarbonate/carbonate ions relative to the concentration of carbon dioxide. Feed and concentrate (reject) pH can also affect the solubility and fouling potential of calcium carbonate, silica, aluminium, organics and oil. Variations in feed pH can also affect the rejection of ions. For example, fluoride, boron and silica rejection are lower when the pH becomes more acidic.

Phosphate & Orthophosphate (PO_4^{3-})

Phosphates, with a valence charge of -3, have a strongly negative charge and a tendency to react with multivalent cations. Calcium phosphate has a very limited solubility at neutral pH, and an even lower solubility at higher pH. If phosphates are present in a feed water to any appreciable extent, unless the water is acidified, the phosphate will likely fall out of solution. Orthophosphate readily forms a very insoluble scale with calcium.

Potassium (K^+)

Potassium is a monovalent cation and is typically found at much lower concentrations than sodium. The salts of potassium are highly soluble and do not cause a scaling problem.

Recovery

Percent recovery is the percentage of feed water which becomes permeate. A higher recovery rate means less feed water is sent to the drain as concentrate. However, if the recovery rate is too high for the system design, larger problems may arise due to scaling and fouling. System recovery is established in the system design, taking into consideration numerous factors such as feed water chemistry, pre-treatment and crossflow velocity. Therefore, the proper recovery at which the system should operate depends on what the system was designed for. By calculating the system recovery, it is easy to quickly determine if the system is operating outside of the intended design. To calculate percent recovery:

$$\%\ Recovery = \frac{Permeate\ Flow\ Rate}{Feed\ Flow\ Rate} * 100\%$$

Reverse Osmosis

Reverse osmosis (RO) is capable of rejecting over 99% dissolved salts (ions), particles, colloids, sugars, organics, pesticides/herbicides and endotoxins/pyrogens from the feed water. An RO membrane rejects contaminants based on both their size and charge. Any contaminant in the feed that has a molecular weight greater than 100 Da is likely to be rejected by an RO membrane. Likewise, the greater the ionic charge of the contaminant, the more likely it will be unable to pass through the RO membrane. For example, an RO membrane easily rejects magnesium and sulfate ions which have a 2+ and 2- charge (divalent), whereas sodium or chloride ions are not as easily rejected because they have a 1+ and 1- charge (monovalent).

RO is very effective in treating brackish, surface and ground water for both large and small flow applications. Some examples of industries that use RO water include municipal drinking water, pharmaceutical, boiler feed water, food and beverage, metal finishing and semiconductor manufacturing. Some of the above process applications use RO membranes to concentrate proteins and sugars. In these types of applications, the concentrate becomes the valuable product and the permeate is the unwanted stream.

Salt passage

Salt passage is simply the inverse of salt rejection; it is the amount of salts (expressed as a percentage) that are passing through the elements. The lower the salt passage, the better the system is performing. A high salt passage may suggest that the membranes require cleaning or replacement.

$$Salt\ Passage\ (\%) = 1 - Salt\ Rejection\ (\%)$$

Salt rejection

Percent salt rejection reveals how effective the membrane elements are at removing particular dissolved solids and other contaminants. It does not reflect the performance of each individual membrane element, but rather how the system as a whole is performing. A well-designed system with properly functioning elements will reject the majority of most feed water impurities depending on the membrane type (please refer to the corresponding specification sheet for a particular element). To determine how effective the elements are at removing contaminants, use the following equation:

$$\begin{aligned} Salt\ Rejection\ \% = {} & Concentration\ of\ Feed\ Water \\ & - \ Concentration\ of\ Permeate\ WaterConcentration\ of\ Feed\ Water\ * 100\% \end{aligned}$$

The higher the salt rejection, the better the system is performing. A low salt rejection for the particular element may suggest that the membranes require cleaning or replacement (refer to MANN+HUMMEL Water & Fluid Solutions various Troubleshooting Guides for more information).

SDI (Silt Density Index)

SDI is an empirical test developed for membrane systems to measure the rate of fouling of a 0.45 micron filter pad by the suspended and colloidal particles in a feed water. This test involves the time required to filter a specified volume of feed at a constant 30 psi at time zero and then after 5, 10 and 15 minutes of continuous filtration. Typical RO element warranties list a maximum SDI of 5.0 at 15 minutes for the feed water. If the SDI test is limited to only 5 or 10 minute readings due to plugging of the filter pad, the user can expect a high level of fouling for the RO. Surface sources typically require pretreatment for removal of colloidal and suspended solids to achieve acceptable SDI.

SDSI (Stiff Davis Saturation Index)

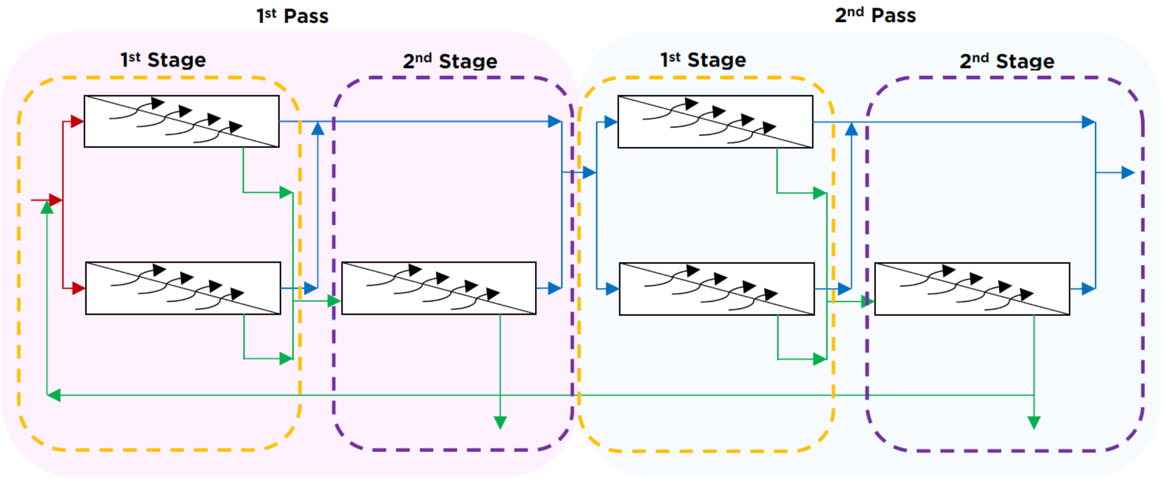
SDSI, in similar fashion as LSI, is a method of reporting the scaling or corrosion potential of high TDS seawater based on the level of saturation of calcium carbonate. The primary difference between SDSI for high TDS seawater and LSI for low TDS brackish water is the effect that increasing ionic strength has on increasing solubility. The solubility of sparingly soluble salts increases with higher TDS and ionic strength, based on the theory that a denser ion population interferes in the formation and/or precipitation of the sparingly soluble salt.

Silica (SiO_2)

Silica (or silicon dioxide) is a complex and somewhat unpredictable subject. Silica reports the total concentration of silicon (as to a long chain. Reactive silica, though it has anionic characteristics, is not counted as an anion in terms of balancing a water analysis but it is counted as a part of total TDS. Unreactive silica is polymerized or colloidal silica, acting more like a solid than a dissolved ion. Silica, in the colloidal form, can be removed by a RO but it can cause colloidal fouling at the front-end of a RO. Colloidal silica, with sizes as small as 0.008 micron can be measured empirically by the SDI (Silt Density Index) test, but only the portion that is 0.45 micron or larger. Particulate silica compounds (i.e. clay, silts and sand) are usually 1 micron or larger and can be measured using the SDI test. Polymerized silica, which uses silicon dioxide as the building block, exists in nature (i.e. quartzes and agates) and can also result from exceeding the reactive silica saturation level. Reactive silica solubility increases with increasing temperature, increases at a pH less than 7.0 or more than 7.8, and decreases in the presence of iron which acts as a catalyst in the polymerization of silica. Silica rejection is pH sensitive, with increasing rejection at a more basic pH as the reactive silica exists more in the salt form than in the acidic form. If silica is present in the feed water at a concentration greater than 20 ppm, the potential for silica precipitation should be evaluated. Silica concentrations in the reject stream should be limited to less than 200 ppm at 25°C (77°F) and near neutral pH values.

Single Pass vs. Double Pass System

Think of a “pass” as a stand-alone system. The difference then between a single pass system and a double pass system is that for the latter, the permeate from the first pass becomes the feed water to the second pass (or second stand-alone system). This results in a higher permeate quality because the water has essentially gone through two systems (the water has passed through the membrane twice). Some or all of the second pass concentrate may be recycled back to the feed to increase overall system recovery.



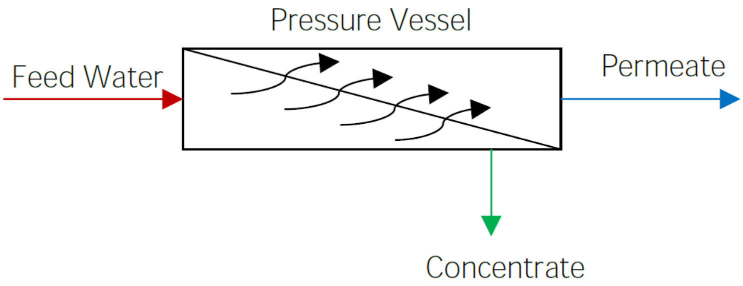
A two pass system; where the permeate of the first pass becomes the feed to the second pass.

Sodium (Na^+)

Sodium is a monovalent cation. The solubility of sodium salts is high and typically does not cause a RO scaling problem.

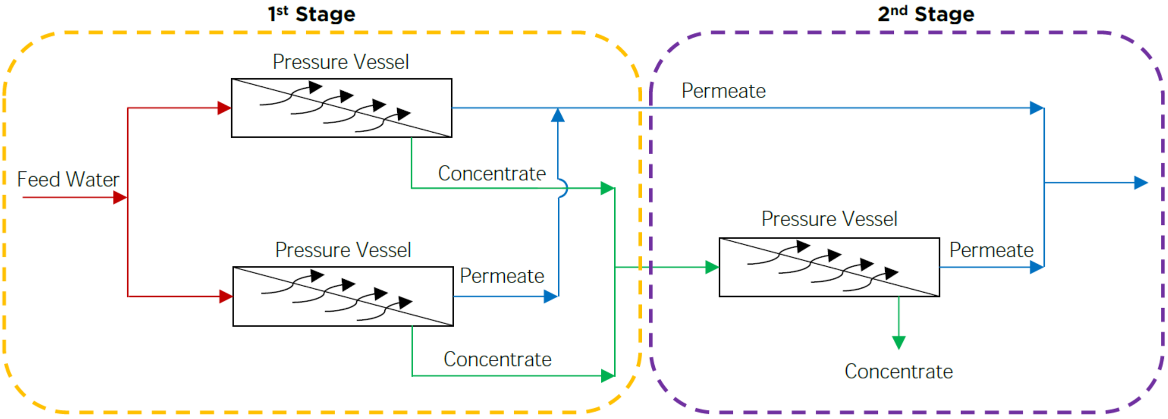
Stage

In a single-stage system, the feed water enters the system as one stream and exits the system as either concentrate or permeate water.



A single stage (and single pass)

In a two-stage system, the concentrate (or reject) from the first stage becomes the feed water to the second stage. The permeate water collected from the first stage is combined with the permeate water from the second stage. Additional stages increase the overall recovery of the system.



A two stage system; where the concentrate from the first stage becomes the feed to the second stage.

Strontium (Sr^{2+})

Strontium is a divalent cation. If strontium is present in relatively small concentrations (0.01 mg/L or more) along with sulfates, they can easily fall out of solution as scale on the membrane surface. Strontium sulfate scale is extremely difficult to redissolve, therefore it is generally controlled with antiscalants.

Sulfate (SO_4^{2-})

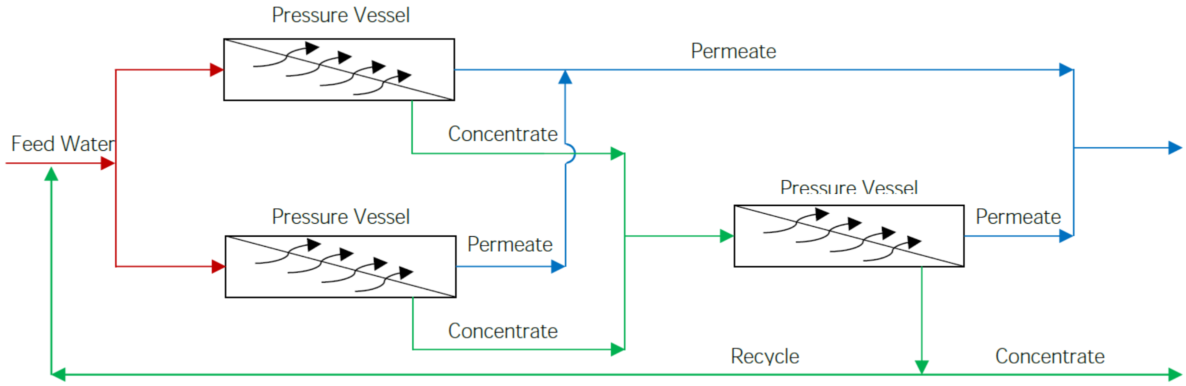
Sulfate is a divalent anion. Sulfates have limited solubility in water, depending on the concentrations of divalent cations also present. The prevention of sulfate scale formation in an RO system is usually performed by reducing or controlling the divalent cations in the raw water. Note that when using sulfuric acid for pH control, the potential for forming sulfate-based scales may increase.

Sulfide (S^{2-})

Sulfides present as a dissolved gas (hydrogen sulfide, H_2S), will fall out of solution as elemental sulfur if oxidized by oxygen from the atmosphere or by chlorine injected into the water for biological control. Hydrogen sulfide gas can be removed by running the water through a degasifier or intentionally oxidizing it using chlorine injection and removing the precipitated sulfur with media filtration prior to the membranes.

System with Concentrate Recycle

If the feed water chemistry and system design allows for it, a concentrate recycle stream can be utilized where a portion of the concentrate stream is fed back to the feed water of the first stage to help increase the system recovery as well as the cross-flow within the pressure vessels.



A two stage system with a concentrate recycle stream back to the feed stream.

TDS (Total Dissolved Solids)

TDS, in water treatment, is the inorganic residue left after the filtration of colloidal and suspended solids and then the evaporation of a known volume of water. TDS is reported as ppm or mg/L. TDS is determined by calculation using the sum of the cations, anions and silica ions. Feed or permeate TDS can also be estimated by applying a conversion factor to the conductivity of the solution. TDS can also be determined in the field by use of a TDS meter. TDS meters measure the conductivity of the water and then apply a conversion factor that reports TDS to a known reference solution (i.e. ppm sodium chloride or ppm potassium chloride). The user is cautioned that TDS levels for waters with a mixture of ions and determined from conductivity measurements may not agree with TDS calculated as a sum of the ions. As a rough rule of thumb for brackish waters, one ppm of total ions in solution correlates to a conductivity of 1.6 micromhos/cm (microSiemens/cm).

Temperature

Temperature is a critical design parameter. It has significant effects on feed pump pressure requirements, hydraulic flux balance between stages, permeate quality and solubility of sparingly soluble salts. As a rule of thumb, every 5°C (41°F) decrease in feed temperature increases the feed pump pressure requirement 10 15%. The hydraulic flux balance between stages (or in other words the amount of permeate produced by each stage) is impacted by temperature. When water temperature increases, the elements located in the front end of the system produce more permeate which results in reduced permeate flow by the elements located at the rear of the system. A better hydraulic flux balance between stages occurs at colder temperatures. At warmer temperatures, salt passage increases due to the increased mobility of the ions through the membrane. Warmer temperatures decrease the solubility of calcium carbonate. Colder temperatures decrease the solubility of calcium sulfate, barium sulfate, strontium sulfate and silica. In practice, RO system design projections should be run at both the highest and lowest expected temperatures.

TOC (Total Organic Carbon)

TOC, an acronym for Total Organic Carbon or Total Oxidizable Carbon, is a non-specific test that measures the amount of carbon organic matter, the actual weight of the organic mass can be up to 3 times higher in natural surface waters. Organics are compounds that contain carbon (with the exception of carbon dioxide, bicarbonate and carbonate), however in water treatment, organics can be classified as naturally occurring (NOM) or man-made. A RO and NF membrane will reject organic compounds and generally, organic compounds with a molecular weight greater than 200 are rejected at levels greater than 99%. The rejection of compounds with molecular weights less than 200 will vary based on molecular weight, shape and ionic charge. As a rough rule of thumb, it is recommended to keep TOC levels below 3 ppm to prevent organic fouling in natural water sources.

Turbidity

Turbidity is determined by a Nephelometer that measures the relative amount of light able to pass through a solution and is reported as NTU (Nephelometric Turbidity Units). The maximum turbidity levels for RO and NF elements is 1.0 NTU for the feed water.

Zinc (Zn^{2+})

Zinc is usually not present in natural water sources, but it is possible to pick up trace concentrations from piping materials. Zinc tends to fall out of solution with increasing pH. As a transition metal, zinc can increase the oxidation potential of oxidizing agents.

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