PFAS Overview

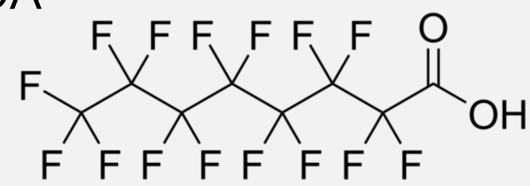
What are PFAS?

Per- and polyfluoroalkyl substances (PFAS)

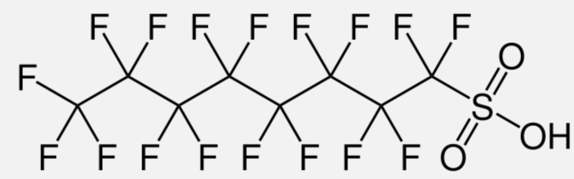
- Present throughout the food supply chain from ingredient water to final packaging
- Levels as low as 7 ppt are hazardous to humans.
- Current CA State notification levels are 5.1 ppt for PFOA and 6.5 ppt for PFOS.
- Current detection level is 2 ppt.
- Cannot be removed from water through conventional coagulation/flocculation/sedimentation/filtration treatment
- Require advanced treatment strategies

Common PFAS

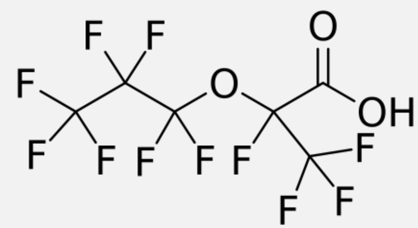
PFOA



PFOS

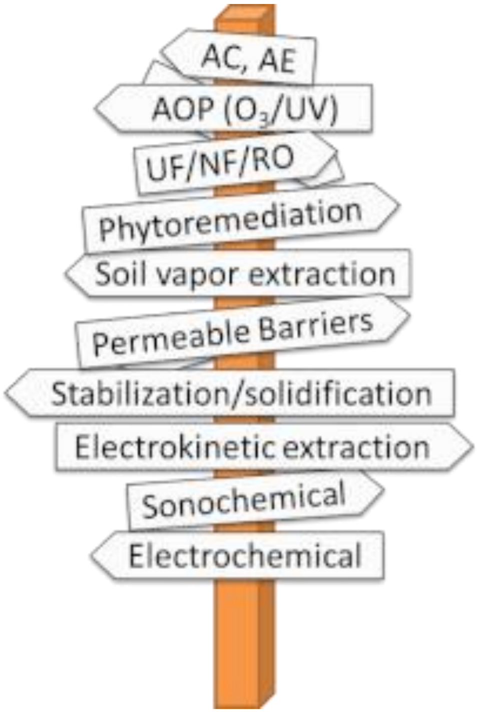


GenX



PFAS Removal Technologies

Technology	PFAS Removal Efficiency	Pros	Cons
Granular Activated Carbon (GAC)	• Poor removal of short chain PFAS	• Well understood technology	• High OPEX and CAPEX; • Large footprint; • Disposal/Reactivation of large volumes of carbon
Ion Exchange Resin (IX)	• Removal of only certain PFAS	• Efficient single-step technology; • Low to medium OPEX	• Non-regenerable in most cases; • Waste management (resin and brine) can be time consuming.
Membrane Processes – Nanofiltration (NF) Reverse Osmosis (RO)	• Effective for PFAS removal	• Efficient process if properly operated and maintained; • Low to medium OPEX.	• Complex operation; • Concentrate treatment/disposal.

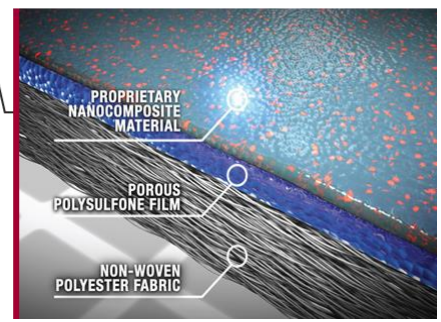


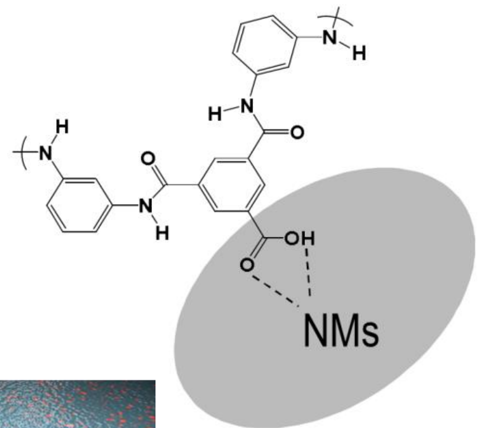
- Membrane processes (NF and RO) provide a broad spectrum of PFAS removal
- RO is widely considered the best technology for PFAS removal

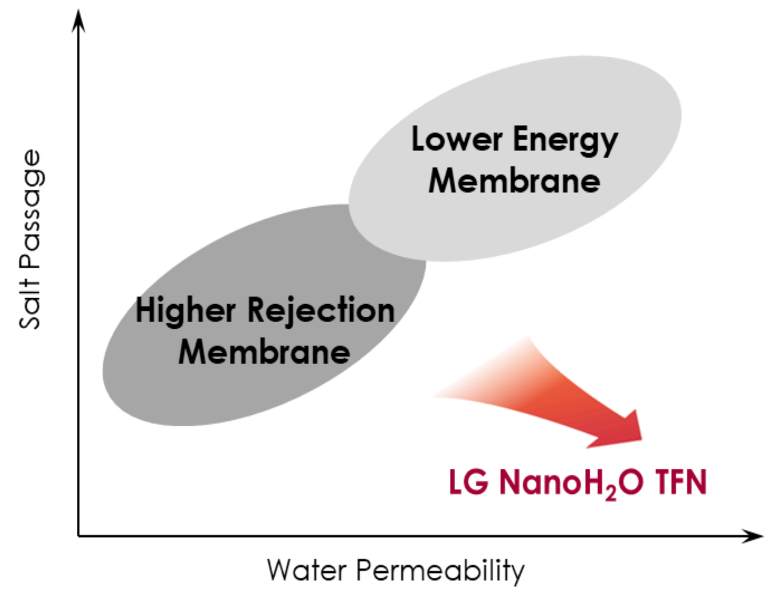
LG Chem Thin Film Nanocomposite (TFN) RO Membranes

Core technology

Embedding nano-materials into RO active layer







- Enhanced free volume
- Increased water permeability
- Best-in-class salt rejection*

*99.89% stabilized salt rejection of SW SR G2, SW GR G2

LG BWRO TFN Membranes

Low and ultra-low pressure

LG BW ES * Energy Saving

Product	Active Membrane Area, ft² (m²)	Permeate Flow Rate, GPD (m³/d)	Stabilized Salt Rejection, %	Minimum Salt Rejection, %	Feed Spacer, Mil
LG BW 400 ES	400 (37)	10,500 (39.70)	99.6	99.5	34
LG BW 440 ES	440 (41)	11,550 (43.70)	99.6	99.5	28

Test conditions: 2,000 ppm NaCl at 25℃ (77℉), 150 psi (10.3 bar), pH 7, Recovery 15%. Permeate flows for individual elements may vary +/-15%.

LG BW UES * Ultra Low Energy

Product	Active Membrane Area, ft² (m²)	Permeate Flow Rate, GPD (m³/d)	Stabilized Salt Rejection, %	Minimum Salt Rejection, %	Feed Spacer, mil
LG BW 400 UES	400 (37)	11,500 (43.5)	99.0	98.0	34
LG BW 440 UES	440 (41)	12,650 (47.9)	99.0	98.0	28

Test conditions: 2,000 ppm NaCl at 25℃ (77℉), 125 psi (8.6 bar), pH 7, Recovery 15%. Permeate flows for individual elements may vary +/-20%

* Also available in 4” and 2.5” configurations

Case Study 1: BGNDRF

PFAS removal from well water

- Objective: Evaluate field performance of Energy-Saving LG Chem TFN BWRO membranes with respect to PFAS removal

Project Background

- PFAS discovered in well water at BGNDRF (Well 2 and Well 4).
- BGNDRF made contaminated water available to evaluate PFAS removal.
- Opportunity to test RO membranes in field.
- Well 2 was selected because of high iron content in Well 4

Feed Water

General Chemistry		Well 2	Well 4
Alkalinity, Bicarbonate (as CaCO3)	mg/L CaCO3	197	199
pH – Aqueous	pH units	7.60	7.90
Turbidity	mg/L	9.8	16.0
Hardness, Total (as CaCO3)	mg/L	2600	2180
Sulfate	mg/L	1800	1790
Chloride	mg/L	674	647
Calcium	mg/L	513	502
Magnesium	mg/L	321	224
Sodium	mg/L	638	445
Silicon Dioxide	mg/L	17.4	17.1
Iron (Total)	mg/L	0.0928	3.37
Conductance, Specific	µmhos/cm	5790	4800
Solids, Filterable Total Dissolved Solids	mg/L	5160	4100
Organics			
Organic Carbon, Total	mg/L	1.26	0.895
PFAS			
Perfluorooctanoic Acid (PFOA)	µg/L	0.240	0.140
Perfluorooctanesulfonic Acid (PFOS)	µg/L	0.0160	0.0150

Case Study 1: BGNDRF

Equipment

Wigen 3-stage RO skid

- 4-inch
- 3:2:1 (x6) with split PVs
  (2 stages used for this trial).
- Interstage boost pumps
- 5-micron cartridge filter
- Antiscalant dosing
- HMI and automated data collection with local storage on PC
- CIP loop

RO Membranes

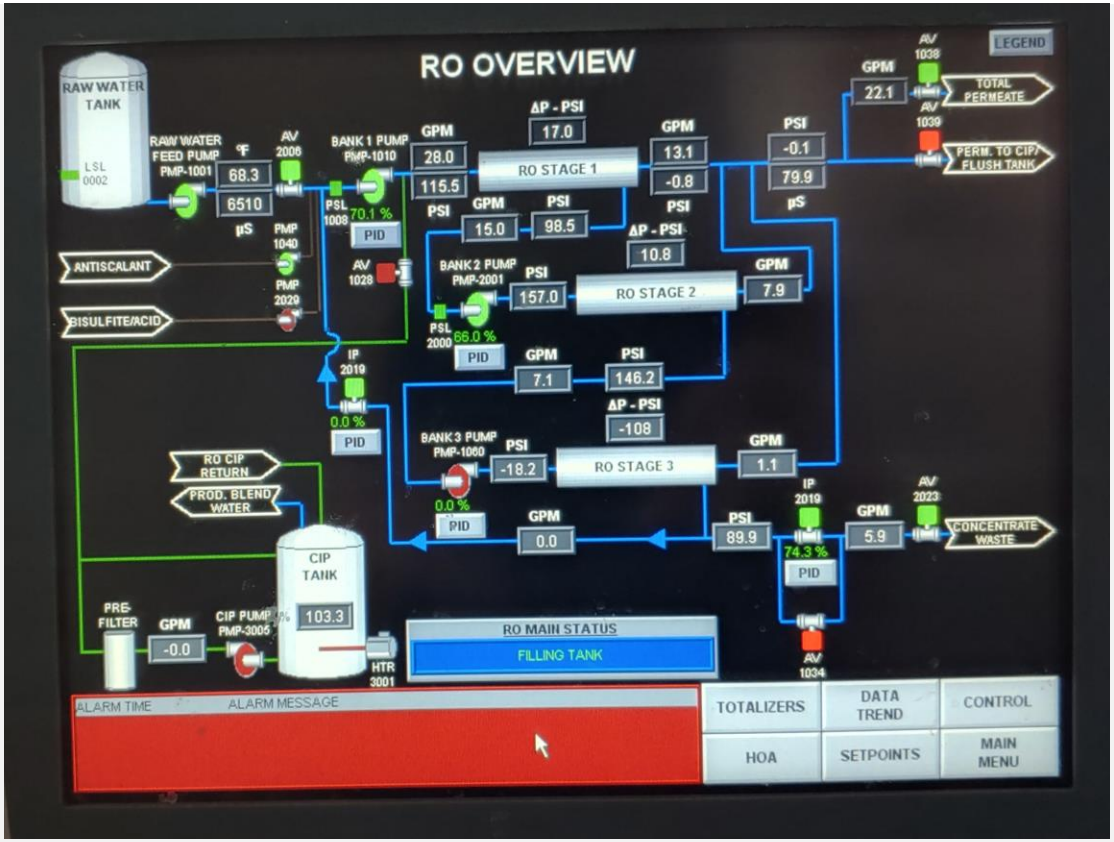
- Energy-saving LG BW 4040 ES

Case Study 1: BGNDRF

Operation at startup

Operating Conditions

- Array: 3:2 x (6) BW 4040 ES
- Number of elements: 30
- Flux: 11.9 gfd
- Permeate flow: 21 gpm
- Recovery: 78%
- Feed TDS: 5,200 mg/L
- Temperature: 20 ºC

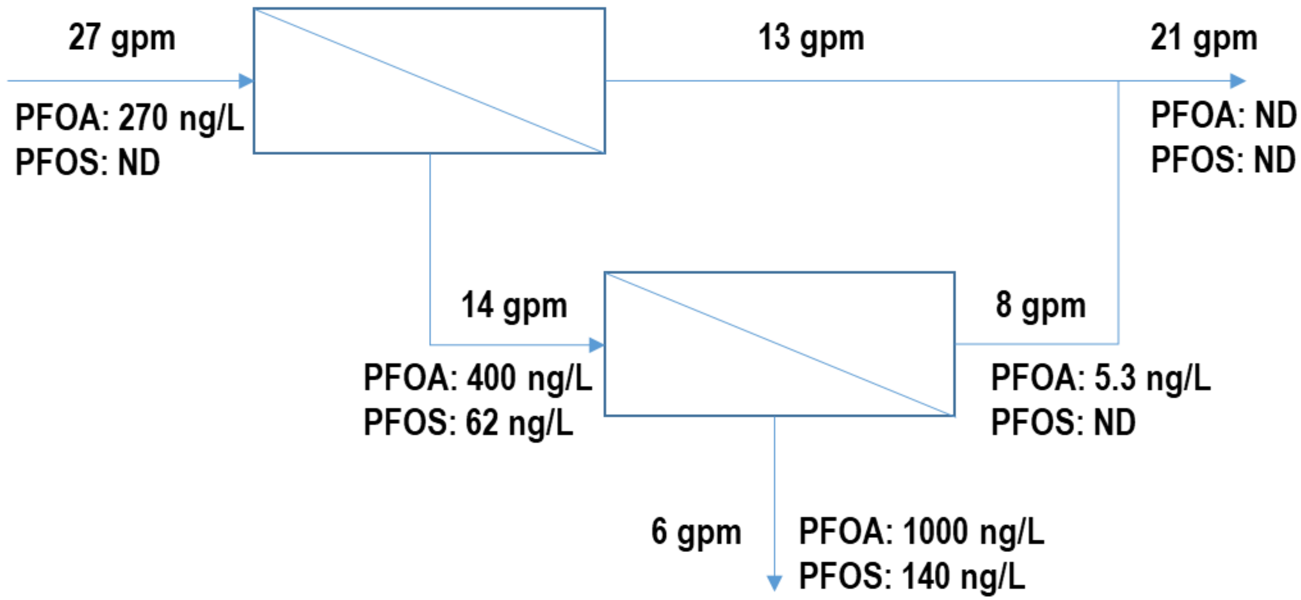


Results

Stage	Feed Pressure, psi	Permeate TDS, mg/L
Stage 1	115	46
Stage 2	157	135
Composite		85

Case Study 1: BGNDRF

PFAS rejection at startup



PFAS concentrations in streams

Constituent	Feed to Stage 1, ng/l	Feed to Stage 2, ng/L	Permeate after Stage 2, ng/L	Concentrate., ng/L	Rejection, %	Permeate Comp., ng/L
PFOA	270	400	5.3	1000	98.7	ND (MDL 3.5)
PFOS	ND (MDL 7.5)	62	ND (MDL 7.9) 3.5 (calc.)	140	94.4*	ND (MDL 7.6)

*Calculated from balance

Case Study 1: BGNDRF

Summary

Current Status

- Startup performance demonstrated high rejection of PFAS (close to 99%).
- There was significant scaling in Stage 2 because of concentrate valve malfunction.
- Skid is currently shut down for cleaning and maintenance.

Next Steps

- Restart operation.
- Perform CIP to assess effect on PFAS removal.

Case Study 2: Water Treatment Plant with AWT

Location undisclosed

Project Background

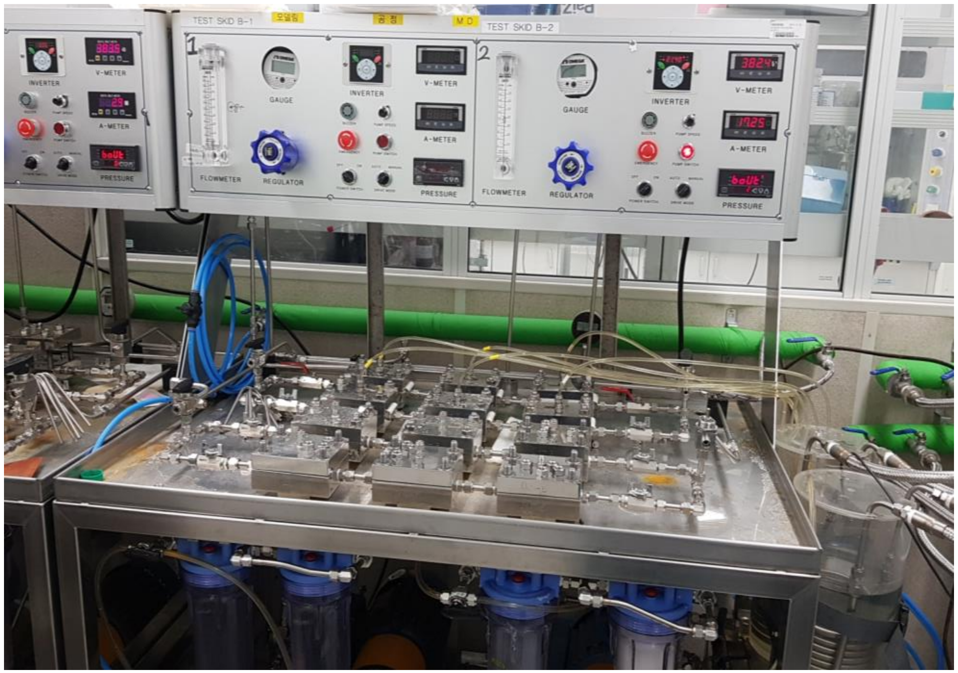
- PFAS was detected in the feed water for WTP.
- Conventional treatment at WTP is inadequate for PFAS removal.
- Pilot study performed to design AWT process.
- Several membranes including LG Chem were tested in qualification trial.

Objectives

- Demonstrate that LG Chem BWRO membranes meet the plant’s targets at design operation:
  - GenX: <5 ng/L (RL) or >95% removal;
  - PFMOAA (Perfluoro-2-methoxyacetic acid): <5 ng/L (RL) or >90% removal;
  - 1,4-Dioxane: <0.07 µg/L (RL) or >80% removal;
  - Salt rejection >98%.
- Perform at least one CIP to verify the membrane stability and performance.

Case Study 2: Water Treatment Plant with AWT

Lab studies



- Membrane: LG BW ES flatsheet
- Test conditions:
  - 2,000 mg/L NaCl, 150 psi, 25 ^{o}C.
  - 20 mg/L GenX, 1,4-dioxane.
- Analysis performed by HPLC/MS
  - Waters e2695 (Detector UV 2998 / Mass Detector 3100)
- Results

Chemical	Rejection, %
GenX	98.6
1,4 - dioxane	97.7

- Benchtop CIP study in progress

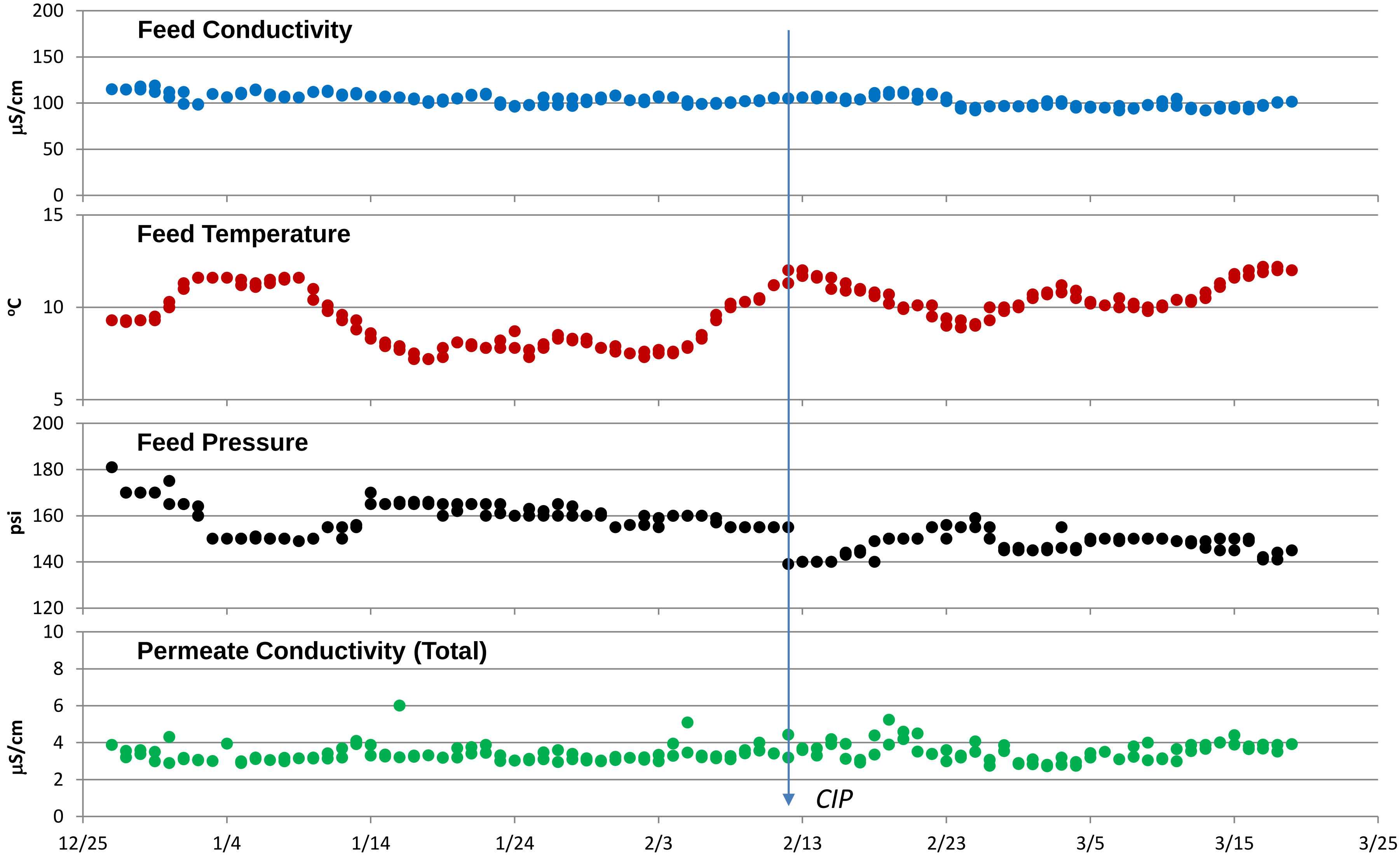
Case Study 2: Water Treatment Plant with AWT

Pilot snapshot

Start-Up and Completion Date	Dec 2018 – Mar 2019
Feed Water Intake	WTP effluent
Pilot Configuration	2:1 pilot skid (4”) with 8 elements per PV
Recovery	82 – 90%
Project Capacity	20.1 gpm (110 m^3/day)
System Flux	14.2 gfd
LG Chem NanoH2O™ Membrane Model	LG BW 4040 ES
Feed Pressure Range	140 – 170 psi

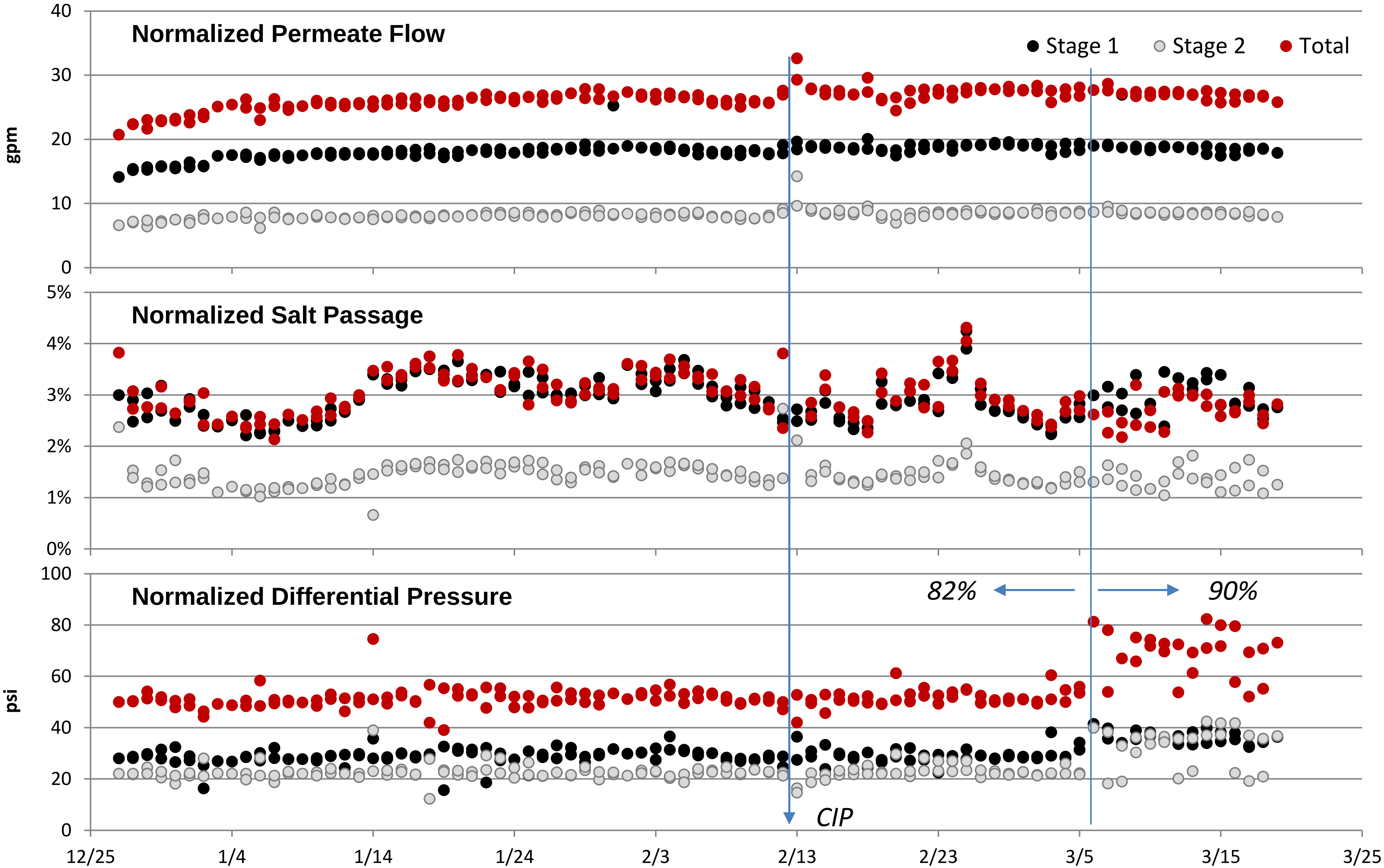
Case Study 2: Water Treatment Plant with AWT

Membrane performance – Operating conditions



Case Study 2: Water Treatment Plant with AWT

Membrane performance – Normalized data



Case Study 2: Water Treatment Plant with AWT

Membrane performance – CEC removal

Water samples for major CEC's and calculated rejection based on MDL (82% recovery)

Analyte	Unit	1/14/2019				2/05/2019 (pre-CIP)				2/18/2019 (post-CIP)			
		Feed	Conc	Perm	Rej	Feed	Conc	Perm	Rej	Feed	Conc	Perm	Rej
1,4-Dioxane	ug/L	0.71	4.8	< 0.07	> 90%	0.8	5.2	< 0.07	> 91%	1.5	11	**0.08**	**94.7%**
GenX	ng/L	6.8	52	< 5.0	> 26%	14	100	< 5.0	> 64%	9.8	68	< 5.0	> 49%
Perfluorobutanesulfonic acid	ng/L	2.6	19	< 2.0	> 23%	2.4	16	< 2.0	> 17%	2.5	17	< 2.0	> 20%
Perfluorobutanoic acid	ng/L	6.9	49	< 2.0	> 71%	5.4	37	< 2.0	> 63%	<5.0	34	< 2.0	
Perfluoroheptanoic acid	ng/L	8.6	62	< 2.0	> 77%	5.9	40	< 2.0	> 66%	5.4	39	< 2.0	> 63%
Perfluorohexanesulfonic acid	ng/L	3.1	23	< 2.0	> 35%	3.6	25	< 2.0	> 44%	4	26	< 2.0	> 50%
Perfluorohexanoic acid	ng/L	11	80	< 2.0	> 82%	7.2	50	< 2.0	> 72%	8.2	57	< 2.0	> 76%
Perfluorooctanesulfonic acid	ng/L	12	84	< 2.0	> 83%	11	72	< 2.0	> 82%	11	74	< 2.0	> 82%
Perfluorooctanoic acid	ng/L	7.8	55	< 2.0	> 74%	7.1	48	< 2.0	> 72%	6.3	43	< 2.0	> 68%
Perfluoro-2-methoxyacetic acid	ng/L	41	110	< 5.0	> 88%	130	330	< 5.0	> 96%	84	190	< 5.0	> 94%
Perfluoropentanoic acid	ng/L	9.5	72	< 2.0	> 79%	7	48	< 2.0	> 71%	8.4	58	< 2.0	> 76%

- No PFAS were detected at 2 ng/L MDL;
- The only detectable event for 1,4 – dioxane showed close to 95% removal, well above target.
- CIP did not have a significant effect on PFAS removal.

Conclusions

- PFAS have been used in manufacturing for nearly 80 years. They are commonly found in surface and ground water and persist in the environment for a long time.
- PFAS pose health concerns through several routes including drinking water.
- Safe levels and discharge regulations are mostly state driven.
- Major treatment options include GAC, IX, and membrane systems (RO, NF).
- Membrane treatment provides operational and economic advantages and more effective removal at lower overall costs.

- TFN membranes can be successfully used for PFAS removal.
- Lab studies and field tests demonstrated high rates of PFAS removal and overall stable performance.