2023 Membrane Technology

CONFERENCE & EXPOSITION

February 20-23, 2023
Knoxville, TN

AMTA
American Membrane Technology Association

American Water Works Association

ULTRA-HIGH PRESSURE REVERSE OSMOSIS (UHPRO) SYSTEM FOR TREATING PFAS/PFOA WASTEWATER FROM AN INDUSTRIAL FACILITY AS PART OF A ZLD PROJECT

Pre-conference workshop: Monday, February 20, 2023

13:00-16:30

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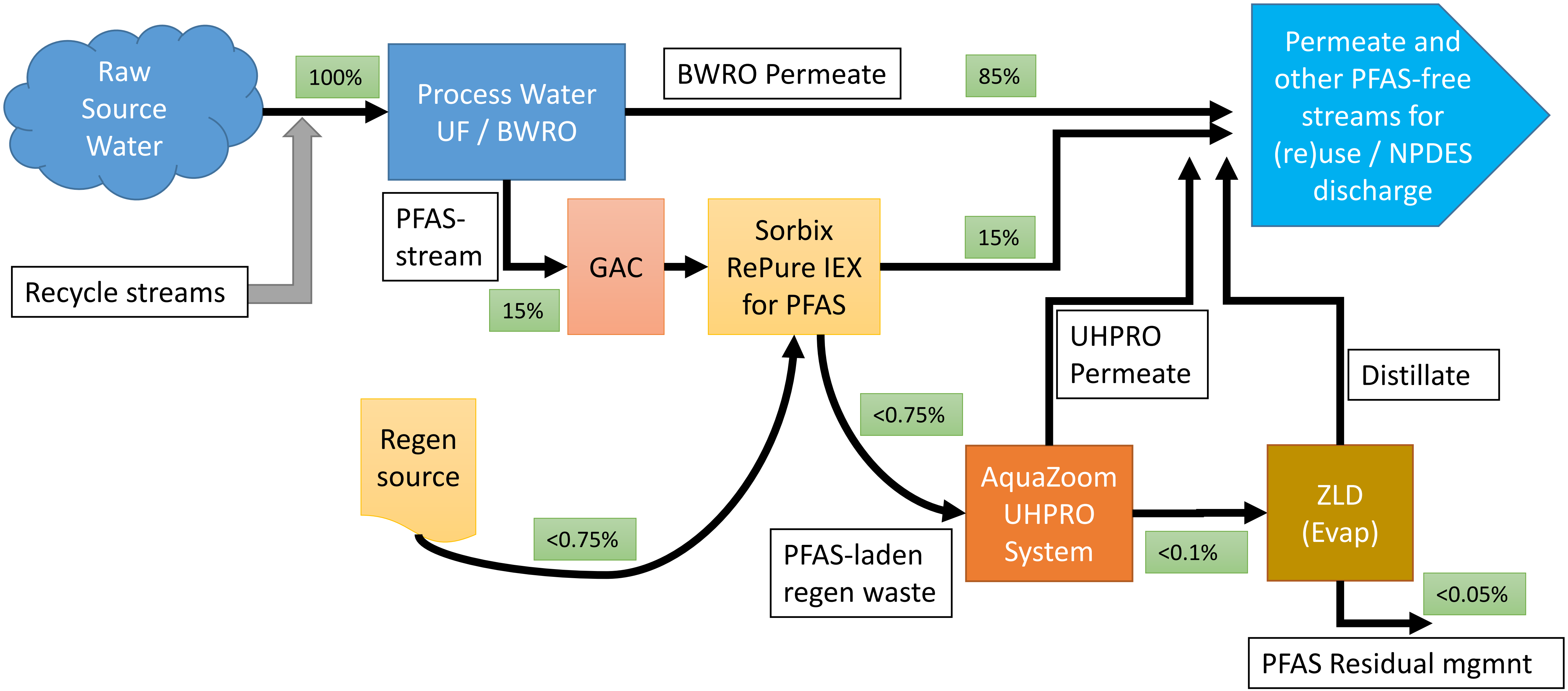
Objectives

1. An industry is reducing its environmental footprint by implementing ZLD on a PFAS-contaminated residual stream from their process water treatment
2. PFAS concentrations in the residual stream were ~1,000 ppm and TDS is ~1wt%
3. Feed conditions required an ultra high-pressure reverse osmosis (UHPRO) system design to concentrate further ahead of the thermal ZLD system
4. Limited data was available in published works for a design basis
5. It was decided that pilot trial was to be performed using a synthetic feed stream as the commercial plant did not exist
6. This work reports this pilot trial that was used as a design basis for the commercial project that is currently under construction

Overall Commercial Process



Key Features of Commercial Process 1/2

1. The process water BWRO reduces the PFAS-laden stream by 6.7X – a standard UF RO process design is used for this part of the process
2. The unique regenerable IEX reduces volume by a factor of > 20X – this relates to IEX regeneration frequency and volume of regenerant needed per cycle
3. The UHPRO reduces the IEX regenerant volume by 7.5X. This relates to TDS and other osmotic pressure contaminants in the spent IEX regeneration waste
4. Total volume reduction with physical/chemical equipment is > 1,000X
5. Even stopping here offers PFAS destruction options due to small flow rate

Key Features of Commercial Process 2/2

6. The evaporation halves the volume (2X) up to limits of about 240,000 TDS
7. Total of > 2,000X concentration of PFAS is achieved. Not 100% ZLD. But close!
8. Final PFAS brine is trucked off site at startup
9. Onsite PFAS destruction is currently being planned and PFAS-free recovered brine can be reused moving closer to true ZLD
10. Major inventive step is > 20X volume reduction by the IEX and this makes the process valuable for a wide range of dilute PFAS projects using BWRO as primary concentration of PFAS, such as drinking water projects

UHPRO KPIs and Design Basis

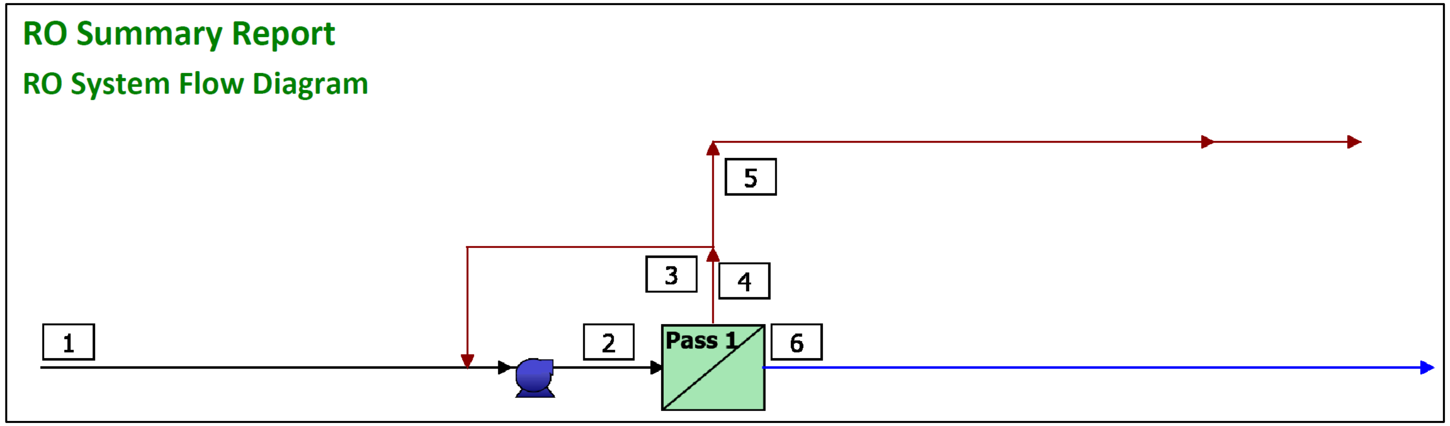
1. Key performance indicators (KPIs) for the UHPRO were derived from a materials balance: Minimum 95% TDS removal (i.e. 555 mg/l permeate TDS) and 98% PFAS removal at 90% recovery

2. Feed specification:

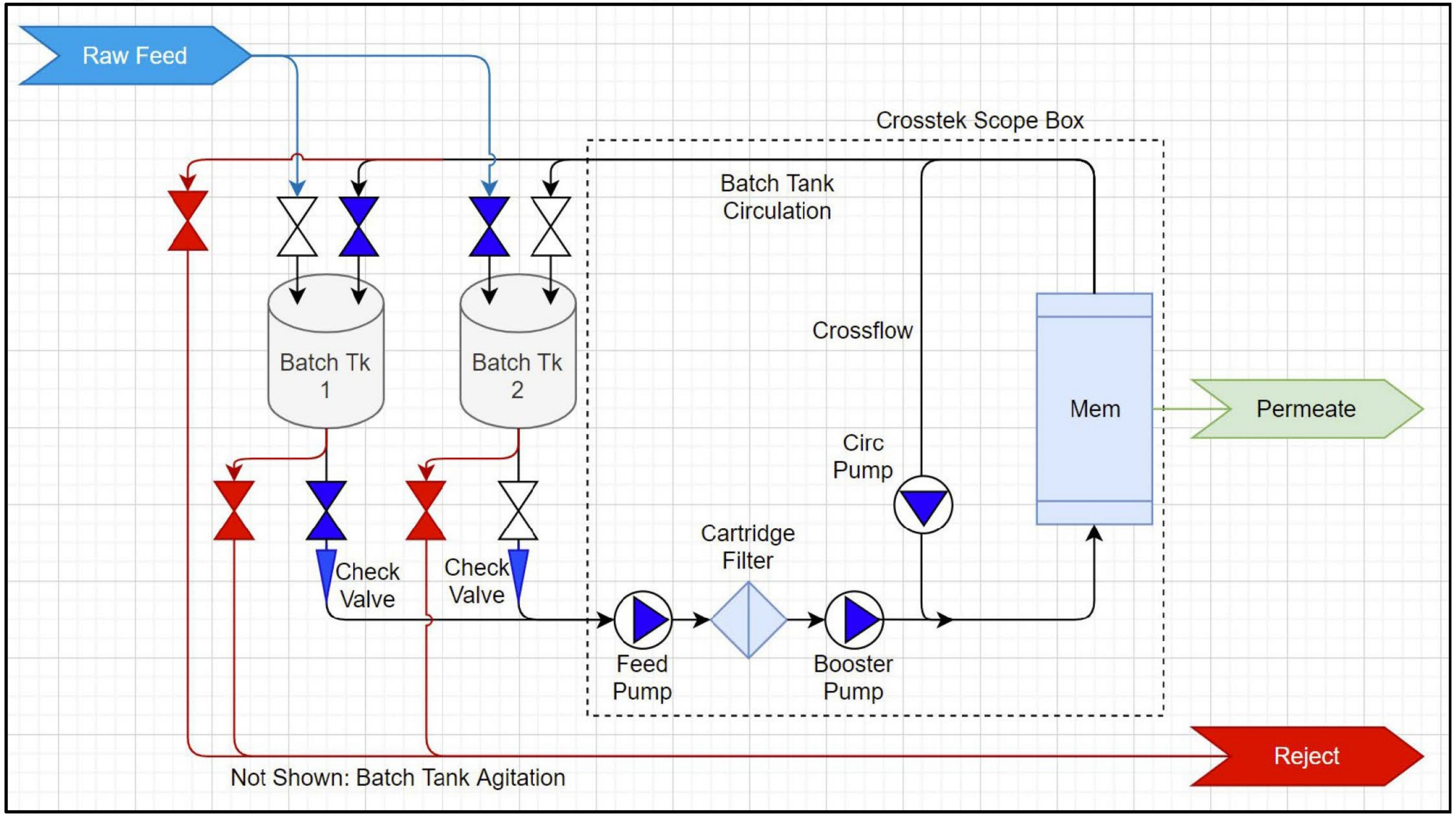
Full Name	Abbreviation	Recipe (mg/L)
Unnamed PFAS Type 1	NoName1	558.74
perfluorobutanoic acid/ Heptaflouro butyric acid	PFBA	155.94
Unnamed PFAS Type 2	NoName2	98.08
Trifluoroacetic acid	TFA	42.98
Unnamed PFAS Type 3	NoName3	34.71
Unnamed PFAS Type 4	NoName4	31.96
Perfluorobutanesulfonic acid	PFBS	11.02
Sulfates added as MgSO4	SO4	300.00
Bromide added as NaBR	Br	100.00
Ethanol	Ethanol	10.00
Sodium Chloride	NaCl	10,000

Preliminary UHPRO design to inform pilot trial

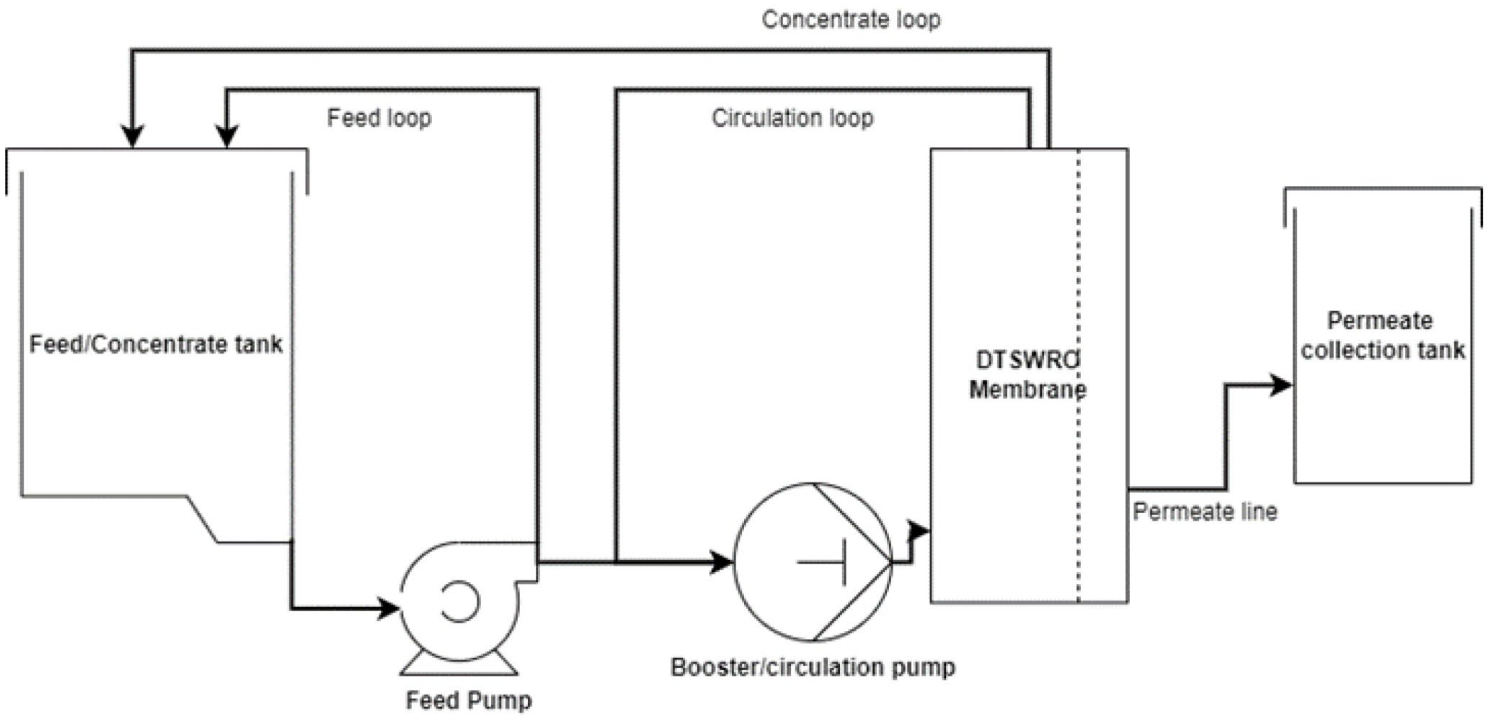
1. Commercial RO projection tool used to study TDS rejection vs flux (1.6 to 4.5 GFD) and RO system temp (77 to 91ºF) at 90% recovery vs KPI of 555 mg/l permeate TDS
2. Permeate TDS projected was 840 to 2,600 mg/l at 90% recovery, exceed targets, and directed the project toward batch RO design
3. Batch operation operates along a concentration curve and lower TDS permeate from start of the run dilutes permeate from the end of the run



Commercial Batch UHPRO Process Schematic



Materials and Methods: Pilot Plant



- Batch tank = 100 gallons with mixing pump that is also RO feed pump
- RO permeate "blend" tank = 100 gallons
- RO booster / circulation pump to set required flow and pressure for the SWRO membrane
- AquaZoom® 8040 disc-tube reverse osmosis (DTRO) membrane used for trials

Performance Data: Pilot Trial Feed Analytical

Full Name	Abbreviation	Recipe (mg/L)	Analytical (mg/l)
Unnamed PFAS Type 1	NoName1	558.74	349.00
perfluorobutanoic acid/ Heptaflouro butyric acid	PFBA	155.94	<191.00
Unnamed PFAS Type 2	NoName2	98.08	110.00
Trifluoroacetic acid	TFA	42.98	64.20
Unnamed PFAS Type 3	NoName3	34.71	31.90
Unnamed PFAS Type 4	NoName4	31.96	58.40
Perfluorobutanesulfonic acid	PFBS	11.02	7.74
Sulfates added as MgSO4	SO4	300.00	2.3
Bromide added as NaBR	Br	100.00	0.00
Ethanol	Ethanol	10.00	NA
Sodium Chloride	NaCl	10,000	9,500

- Feed was prepared to recipe
- Sample of feed was sent to lab for analytical to confirm analytical accuracy
- High Cl- caused significant interference with analytical methods
- This has ramifications for reliability of measurements from commercial labs
- An area worth studying further as regulations increase around PFAS in public water systems, especially with regards to discharge permits for industrial operations

Performance Data: Flux, press, temp, TDS rejection

Sample:	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Type	Instant 1	Instant 2	Instant 3	Instant 4	Blend
time (minutes)	0.00	105.45	161.82	190.91	190.91
Concentration Factor Based on CL	1.00	2.00	5.00	12.73	12.73
rejection (1-P(tds)/C(tds))	99.4%	99.6%	99.7%	93.5%	99.8%
Mass removal TDS	99.4% (inst.)	99.1% (inst.)	98.6% (inst.)	30.4% (inst.)	97.7%
Flux (gfd)	7.16	7.16	7.16	3.25	7.16 (ave)
Pressure (PSI)	250.00	400.00	550.00	1700.00	NA
Temperature Celsius	22.50	22.10	28.60	30.00	26.00

- TDS rejection drops below target at ~ 6X conc. Factor / 83% recovery, confirming projections were correct, and affirming the decision to operate in batch mode to meet TDS KPIs
- Flux remained stable up to the last 20 minutes where pressure hit 1,700 psi in the membrane feed, and the system switched from flux control to pressure control and flux dropped per the concentration in the brine

Performance Data: PFAS/PFOA rejection

Sample:	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Concentration Factor Based on CL	1.00	2.00	5.00	12.73	12.73
Type	Instant 1	Instant 2	Instant 3	Instant 4	Blend
PFBA (mg/l) Permeate	0.00	0.00	0.00	0.00	0.00
PFBS (mg/l) Permeate	0.06	0.03	0.08	11.90	0.17
NoName3 Permeate	0.1	0.1	0.3	40.4	0.4
PFBA (mg/l) Batch tank	156.00			<191.00	< 191.00
PFBS (mg/l) Batch tank	11.10			149.00	149.00
PFBS mass removal	99.4% (inst.)	99.7% (inst.)	99.2% (inst.)	-7.2% (inst.)	98.5%
NoName3 (mg/l) Batch tank	31.9			280.0	280.0

- PFAS rejection drops below target at ~6X conc. factor / 83% recovery, affirming the decision to operate in batch mode to meet 98% PFAS rejection KPI
- Three PFAS shows good estimated intrinsic rejection in samples 1 through 3, but dropped significantly for sample 4. This could be feature of the PFAS / low flux / high temperature, but is addressed well by batch operation (Sample 5)

Performance Data: KPI analysis (interpolated)

		Batch average rejection and values			
Compound	**Feed (mg/l)**	**Blended permeate (mg/l) 12.73X**	**Rejection 12.73X**	**Blended permeate est. (mg/l) 10X**	**Rejection 10X**
Chloride	5500	130	97.64%	77	98.6%
Sulfate	*300*	1.2	99.60%	0.6	99.8%
Bromide	*100*	2.3	97.70%	1.3	98.7%
PFBA	156.0	0.0443	99.94%	< 0.0443	> 99.94%
PFBS	11.1	0.166	98.5%	0.085	99.2%

- Pilot trial showed that KPIs were achieved by the batch operation

Summary

1. An industry was reducing its environmental footprint by implementing ZLD on a PFAS-contaminated residual stream from their process water treatment
2. OAL process comprised UF/BWRO/GAC/IEX/UHPRO/EVAP and reduced PFAS water volume > 2,000X enabling ease of PFAS destruction
3. A batch UHPRO system was designed and was pilot tested using synthetic feed
4. The batch pilot trial was run with a commercial AquaZoom 8040 DTRO membrane with pressure rating 1,740 psi. Trial pressure ran up to 1,700 psi
5. Pilot showed flux 7.15 GFD down to 3.25 GFD; 1wt% to 11wt% TDS; chloride rejection of 98.6% at 10X conc factor; >99.2% rejection of PFAS/PFOA at 10X
6. Results enabled design of a commercial plant, currently under construction
7. Process has broad promise for sequestering PFAS from dilute, large-volume streams, into small-volume concentrated streams for practical PFAS destruction implementation

Equipment Photographs

Acknowledgements

- Pilot and Project Team:
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    - Chris Lehrman, Technical Director
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  - Crosstek Membrane Technology
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Thank you. Any questions?

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