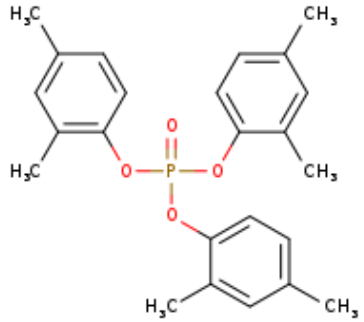
Performance of Pickering 5-8 FRF Purification Skids

STLE Toronto Section Meeting

October 15, 2024 • Andrew Sit

Introduction



Trixylyl phosphate

Steam turbine Electrohydraulic Control (EHC) systems at OPG Nuclear and most other modern nuclear and thermal power plants use phosphate ester-based Fire Resistant Fluids (FRF) hydraulic fluids.

Older units, such as Pickering Units 1 & 4, use lubricating oil as EHC fluid.

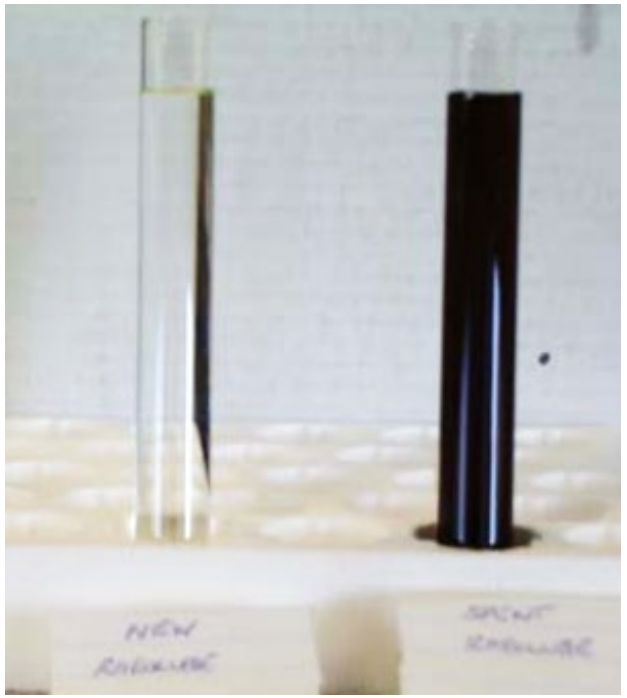
Phosphate ester FRFs are exceptionally suited for purpose because of their excellent fire resistance and lubricating properties.

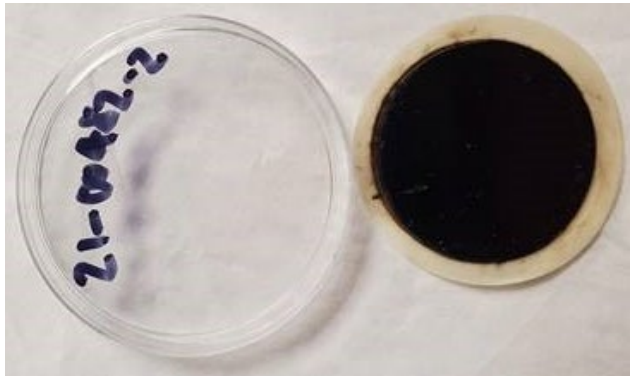
Phosphate ester fluids can be low maintenance and provide long service life, but many operators are challenged with rapid fluid degradation problems.

Introduction

FRF undergoes degradation in service due to:

- High shear stress from constant volume HP pumps
- Micro-dieseling of air bubble ingress into HP pumps
- Hydrolysis (de-esterification) from high water content
- Contaminants:
  - Self-generated: acids, phenols, varnish, carbon
  - External: metal and aminic ions from purification media, water, etc.





Application

OPGN FRF Supply / Power Packages

Consists of:

- Reservoir
- Pumps
- Mechanical and purification filters
- Coolers / heaters
- Vapor extraction fans and/or breathers
- Pressure regulator
- Instrumentation

Pickering

Darlington

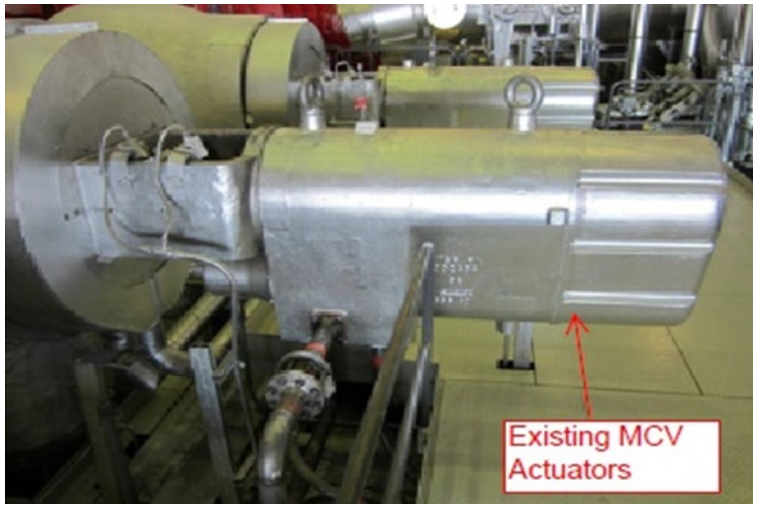
Application

Electrohydraulic Control (EHC) Control Valves

EHC control valves include (typically):

- **Governor valves**: controls the steam flow to the HP turbine or reheaters.
- **Over-speed trip valves**: provides protection against turbine over-speed (and potential catastrophic failure) in event of a load rejection or governor failure.
- **Emergency stop valves**: rapidly cuts off main steam supply during turbine trip or shutdown.
- **Intercept valves**: rapidly cuts off steam supply to LP turbines during turbine trip or shutdown.

Pickering



Darlington

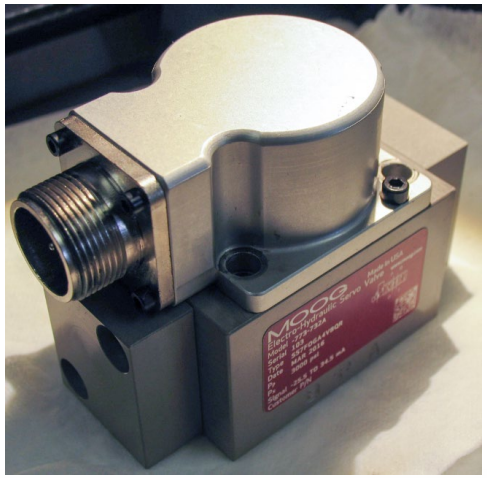
Application

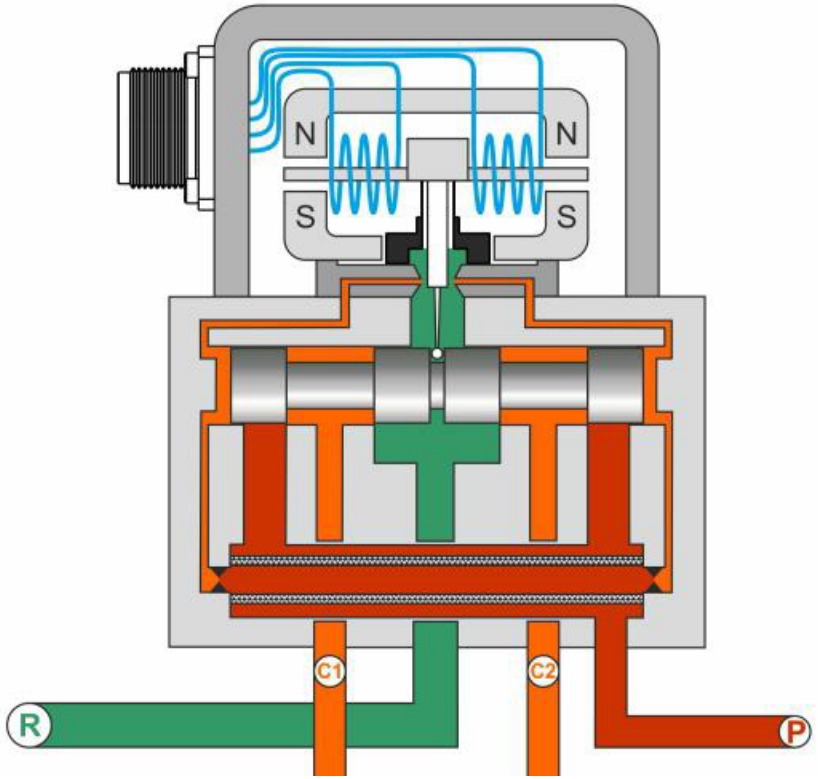
Servo-valve

An electrically-operated valve that controls hydraulic fluid is sent to an actuator. Servo-valves are often used to control powerful hydraulic cylinders with a very small electrical signal.

Valve spool is moved by fluid pressure to balance fluid and electric motor forces using a feedback wire.

Spool clearance is 1 to 4 µm, and is very sensitive to fluid contamination.

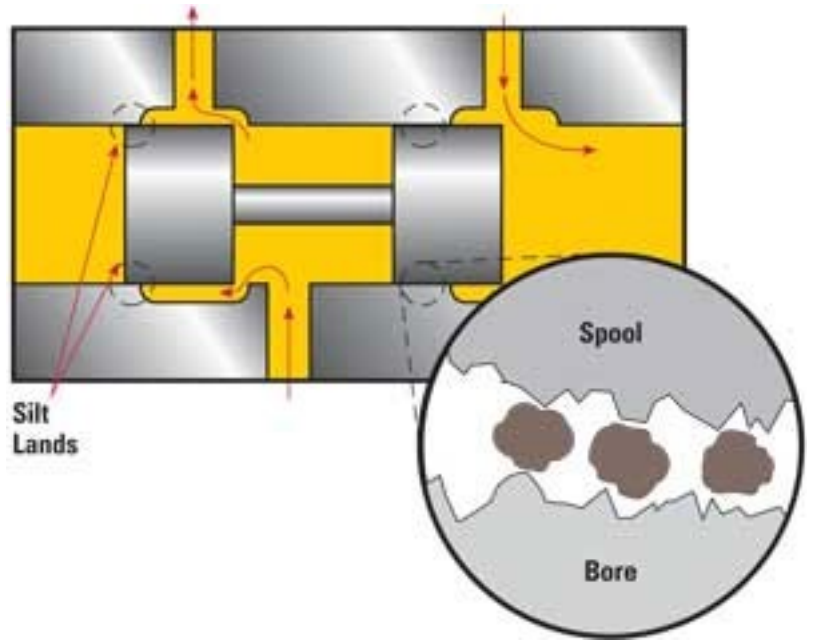




Application

Control Valve Problems

- Stiction and jamming:
  - Electrohydraulic valves, especially servo-valves, are susceptible to stiction and jamming due to fluid contamination by:
    - Varnish deposits
    - Gels from metal salts of phosphate ester decomposition products
    - Ultrafine hard particle < 5µm not removed by system filtration.



Monitoring

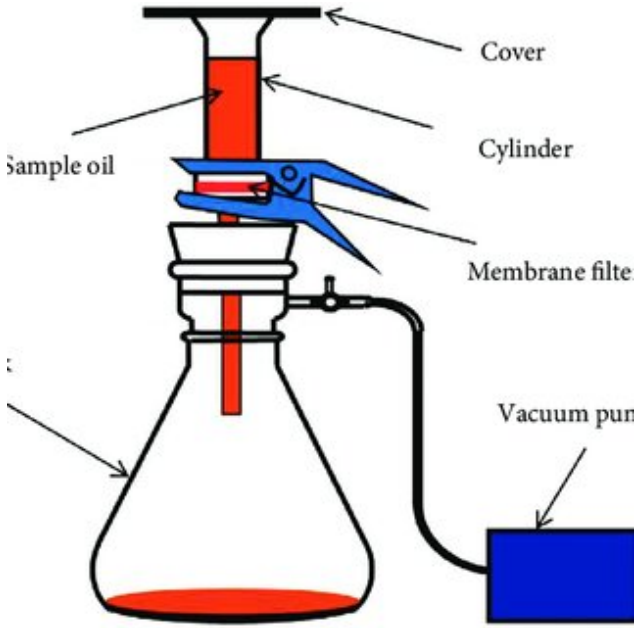
Membrane Patch Colorimetry (MPC)

MPC measures the insoluble colour bodies (soft contaminants) of an oil and is a leading indicator of its varnishing potential.

Original approved as ASTM D7843 in 2013 for in-service turbine oils, the method has been modified for use with EHC phosphate ester FRFs.

The method mixes the fluid with a non-polar solvent and allows time for the soft contaminants to agglomerate before pass the mixture through a 0.45µm patch.

Colour of the patch is measured by a colorimeter and reported as △E value in CIE LAB colour space – this value is also referred to as the MPC value.



Monitoring

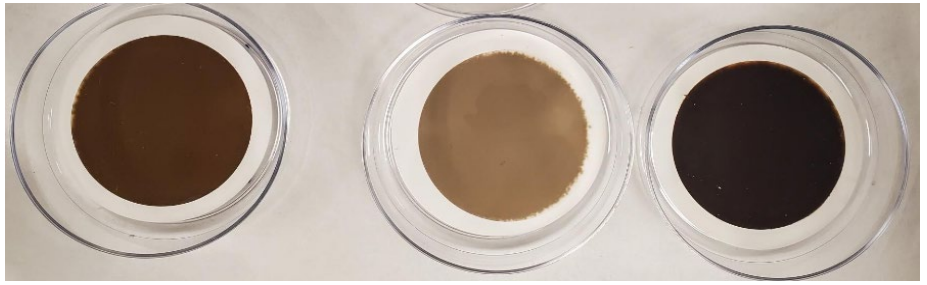
Membrane Patch Colorimetry (MPC)

Additional useful data from MPC is the “patch weight”, or the mass of the deposits on the patch, providing an indicator of the contaminant loading of the fluid.

Example: Pickering FRF samples (May 31, 2021): Unit 5 has 0.318 g of insoluble per L, or over 1.2 kg in the system.

Pickering

	Unit 5	Unit 6	Unit 7
MPC	70	49	78
a + b	28	19	6.8
Patch weight [g]	0.0159	0.0079	0.0154
Contaminant loading [g/L]	0.318	0.158	0.308



Monitoring

Parameters of interest to the project:

- Water content (control parameter)
- Acid Number (control parameter)
- Resistivity (control parameter)
- Membrane Patch Colorimetry or MPC (diagnostic parameter)
- MPC Patch Weight (diagnostic parameter)
- RULER Phenol Area (diagnostic parameter)
- HP filter dP (not a chemistry parameter)

Maintenance

Combination Purification Skid

New skids are commercially available that provide total fluid condition by combining dehydration, electrostatic separation, acid and soluble contaminant removal functions in a single package.

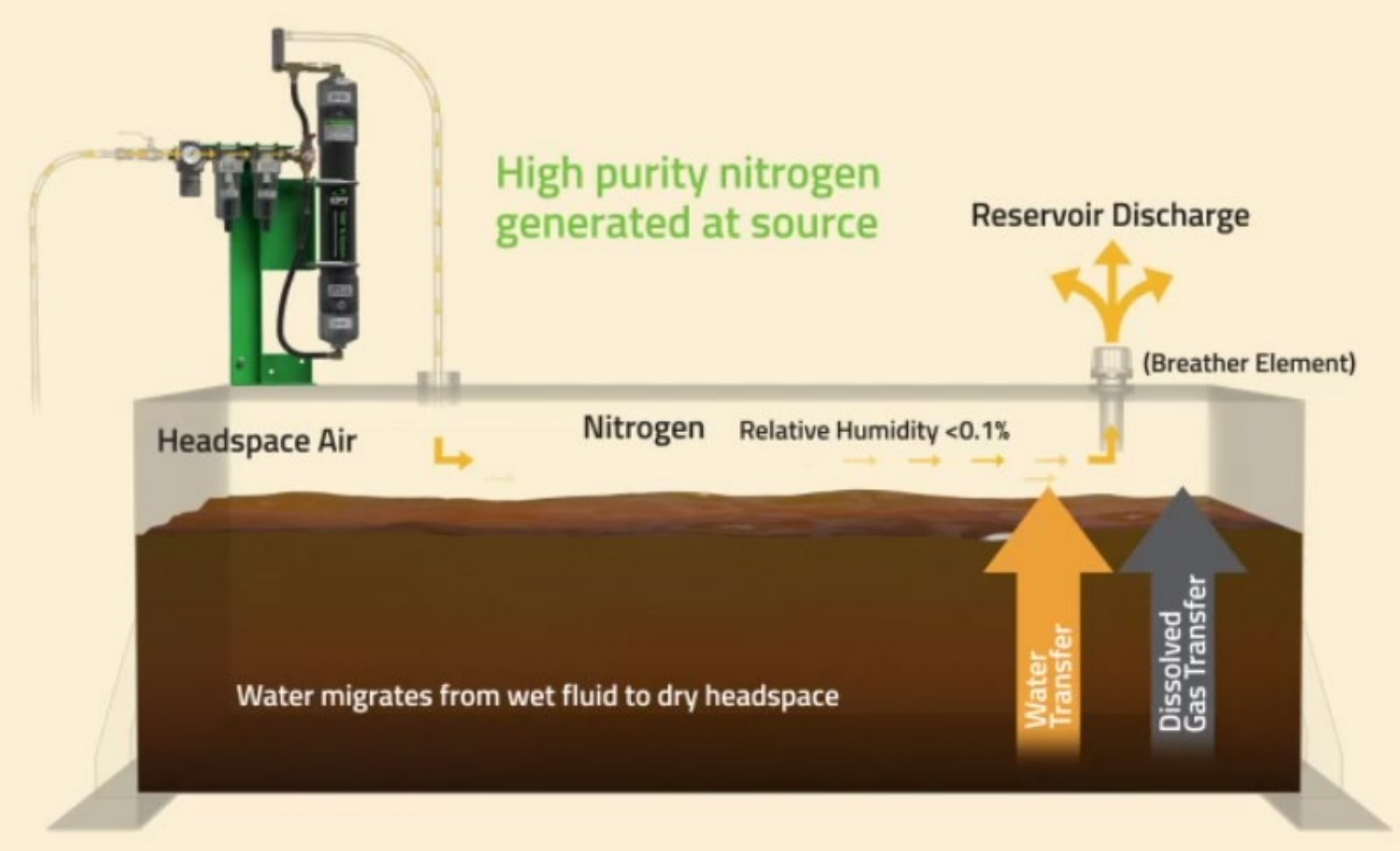
This has been used at Bruce A.

Implemented at Pickering starting Q3 2023.

Maintenance

Water Removal

A dry gas generator, using compressed air and a membrane dryer, continually purges and blankets the headspace in the fluid reservoir with dry air or nitrogen gas, and gently and effectively removed moisture from the fluid, at low cost and maintenance.

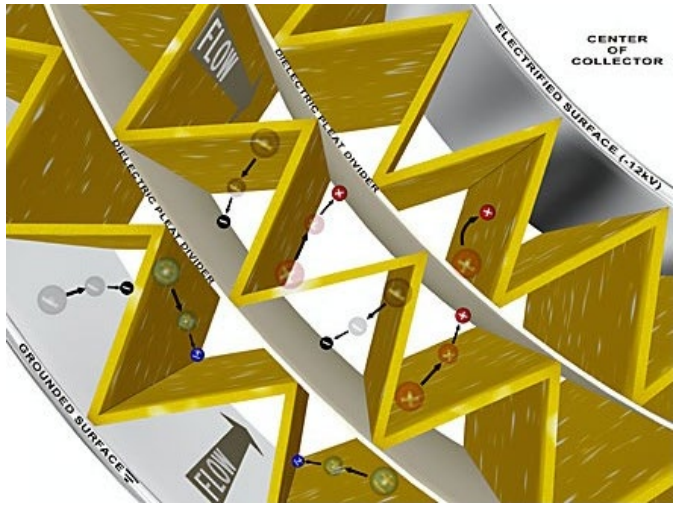


Maintenance

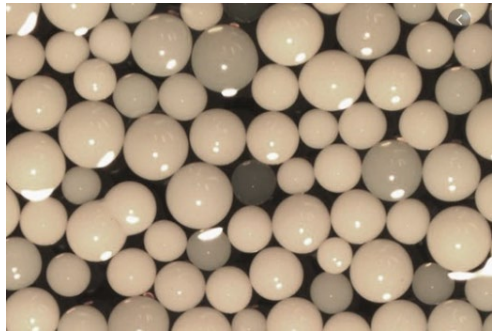
Microfine and Soft Body Particle Removal

Electrostatic separation directs fluid flow between two electrostatically charged plates, and attracting particles to the plates and has shown to be highly effective at removing microfine soft and hard particle, that would not be captured with mechanical filtration.

This method needs high resistivity and low water content so that the electrostatic charge does not dissipate through the fluid.



Maintenance



Acid Removal – IX Resin

Since the 1980's, IX resins have been used successfully for FRF acid and soluble contaminant removal.

IX resins for usage are dried to remove moisture but will still increase FRF water content when first placed in service, hence the importance of dry gas blanketing.

IX resins remove acids, soluble varnish and phenols by adsorption rather than ion exchange.

FRF should be fairly clean before using IX resin as highly contaminated fluid will blank adsorption sites rapidly.

Results

Unit 7 (2023)

EPT™ CLEAN OIL

Company Ontario Power Generation
Site: Pickering Nuclear
Unit: Unit 7
Reservoir Size: 3409 Liters / 901 Gal
Oil Type: Reolube Turbofluid 46 XC

PO/SO #: Prepaid
Contact: Daniel Guerin
Sample Date: 12-Dec-23
Received Date: 15-Dec-23
Date Issued: 21-Dec-23
Report Authorized by: Alicia Robinson

VISION

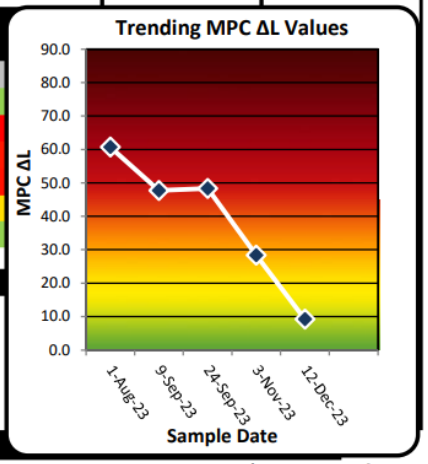
Comments

The sample taken on 12-Dec-23 has a clear & bright appearance and no odour. The fluid's acid number is above target; a small strong acid component was also detected. The fluid's moisture content is within target. The fluid's viscosity is within target. The fluid's ISO particle count is within target. The fluid's resistivity at 20 C is above the application's condeming limit and is within target. The oil's color level is above target. The fluid's contaminant phenol level is above target. The patch weight at 0.45 µm is within target. The MPC ΔL is in the good range (< 20) suggesting that a relatively low level of fine breakdown products is present in the fluid (see filter micrographs below). Spectrographic analysis reveals low levels of dissolved metals that are within target.

	AN D664	SAN D664	H2O D6304	Viscosity* (cSt) D445		ISO Code ISO 4406	ISO (particles / mL) ISO 11500			Resistivity D1169 (20°C)	Color D1500	Phenol Area D6971
Sample Date	(mgKOH/g)		(ppm)	40 °C	100 °C	4/6/14 µm	4 µm	6 µm	14 µm	(GΩ·cm)		(µC)
Target	0.06	N/A	200-500	45.8	5	≤ 16/14/10	≤ 640	≤ 160	≤ 10	≥ 10.0	≤ 3.0	< 2400
1-Aug-23	0.11	N/A	252	45.6	N/A	13/11/8	44	14	2	9.15	N/A	4216
9-Sep-23	0.11	N/A	302	45.6	N/A	12/9/4	29	5	0	20.4	4.7	2584
24-Sep-23	0.11	0.01	285	45.0	N/A	12/10/6	35	9	0	14.5	4.6	2709
3-Nov-23	0.11	N/A	190	45.6	N/A	15/11/6	202	13	1	20.4	3.7	3071
12-Dec-23	0.08	0.01	456	45.3	N/A	13/10/7	63	10	1	20.4	3.3	3006

	Foaming Characteristics D892 (24°C)			Patch Weight and Colorimetry D7843		
Sample Date	Tendency (mL)	Stability (mL)	Time (s)	ΔWt (mg)	MPC Δa + Δb	MPC ΔL
Target	≤ 200	0	< 600	≤ 4.0	< 10.0	≤ 20.0
1-Aug-23	N/A	N/A	N/A	3.5	20.5	60.7
9-Sep-23	N/A	N/A	N/A	2.4	16.8	47.7
24-Sep-23	N/A	N/A	N/A	2.6	17.3	48.3
3-Nov-23	N/A	N/A	N/A	0.7	12.5	28.4
12-Dec-23	N/A	N/A	N/A	0.4	8.4	9.2

Filtration Micrograph(s) in Chronological Order (L to R)



#17 3900-106th Ave SE, Calgary, AB T2C 5B6 403.246.3044, lab@cleanoil.com

*Outsourced Test

Unit 6 (2024)

EPT™ CLEAN OIL

Company Ontario Power Generation
Site: Pickering Nuclear
Unit: Unit 6
Reservoir Size: 3100 Liters / 819 Gal
Oil Type: Reolube Turbofluid 46 XC

PO/SO #: Prepaid
Contact: Sam Pileggi/Sylvester English
Sample Date: 05-Sep-24
Received Date: 12-Sep-24
Date Issued: 19-Sep-04
Report Authorized by: Matt Hobbs

VISION

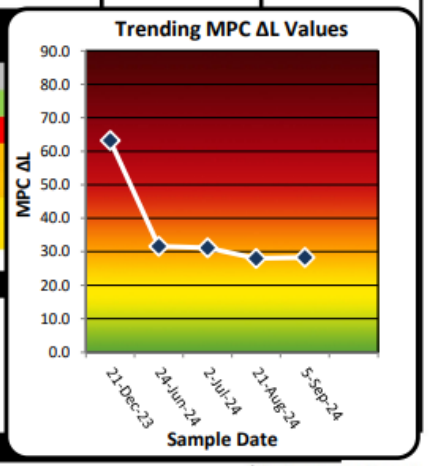
Comments

The sample taken on 05-Sep-24 had a dark appearance and no odour. The fluid's acid number was above target. The moisture content was below target. The fluid's viscosity was within target. The ISO particle count was within target. The fluid's resistivity at 20.0 C was above the condeming limit and was within target. The oil's color was above target. The fluid's contaminant phenol levels was within target. The fluid's 0.45 µm patch weight was within target. The MPC ΔL was in the elevated range (20 - 50) suggesting that a high level of fine breakdown products was present in the fluid (see filter micrographs below). The patch's low MPC Δ(a + b) further suggests that these contaminants are primarily the result of high temperature degradation (microdieseling, sparking etc.). This level of contamination will become a problem within the system in the immediate future. The spectrographic analyses reveaed low levels of dissolved metals that were within target.

	AN D664A	SAN D664A	H2O D6304	Viscosity* (cSt) D445		ISO Code ISO 4406	ISO (particles / mL) ISO 11500			Resistivity D1169 (20°C)	Color D1500	Phenol Area D6971
Sample Date	(mgKOH/g)		(ppm)	40 °C	100 °C	4/6/14 µm	4 µm	6 µm	14 µm	(GΩ·cm)		(µC)
Target	0.06	N/A	200-500	45.8	5	≤ 16/14/10	≤ 640	≤ 160	≤ 10	≥ 10.0	≤ 3.0	< 2400
21-Dec-23	0.14	N/A	381	44.9	N/A	12/11/8	36	11	1	9.75	5.7	2868
24-Jun-24	0.08	N/A	370	45.7	N/A	8/6/5	2	1	0	16.9	4.1	2824
2-Jul-24	0.07	N/A	297	46.2	N/A	10/9/7	10	3	1	14.4	4.1	2572
21-Aug-24	0.08	N/A	247	45.5	N/A	8/5/3	2	0	0	12.1	4.3	1800
5-Sep-24	0.07	N/A	167	45.4	N/A	10/9/5	10	3	0	11.2	4.4	1726

	Foaming Characteristics D892 (24°C)			Patch Weight and Colorimetry D7843		
Sample Date	Tendency (mL)	Stability (mL)	Time (s)	ΔWt (mg)	MPC Δa + Δb	MPC ΔL
Target	≤ 200	0	< 600	≤ 4.0	< 10.0	≤ 20.0
21-Dec-23	N/A	N/A	N/A	4.0	21.4	63.2
24-Jun-24	N/A	N/A	N/A	1.0	13.5	31.6
2-Jul-24	N/A	N/A	N/A	1.3	14.0	31.2
21-Aug-24	N/A	N/A	N/A	0.8	13.6	28.0
5-Sep-24	N/A	N/A	N/A	1.1	13.8	28.3

Filtration Micrograph(s) in Chronological Order (L to R)



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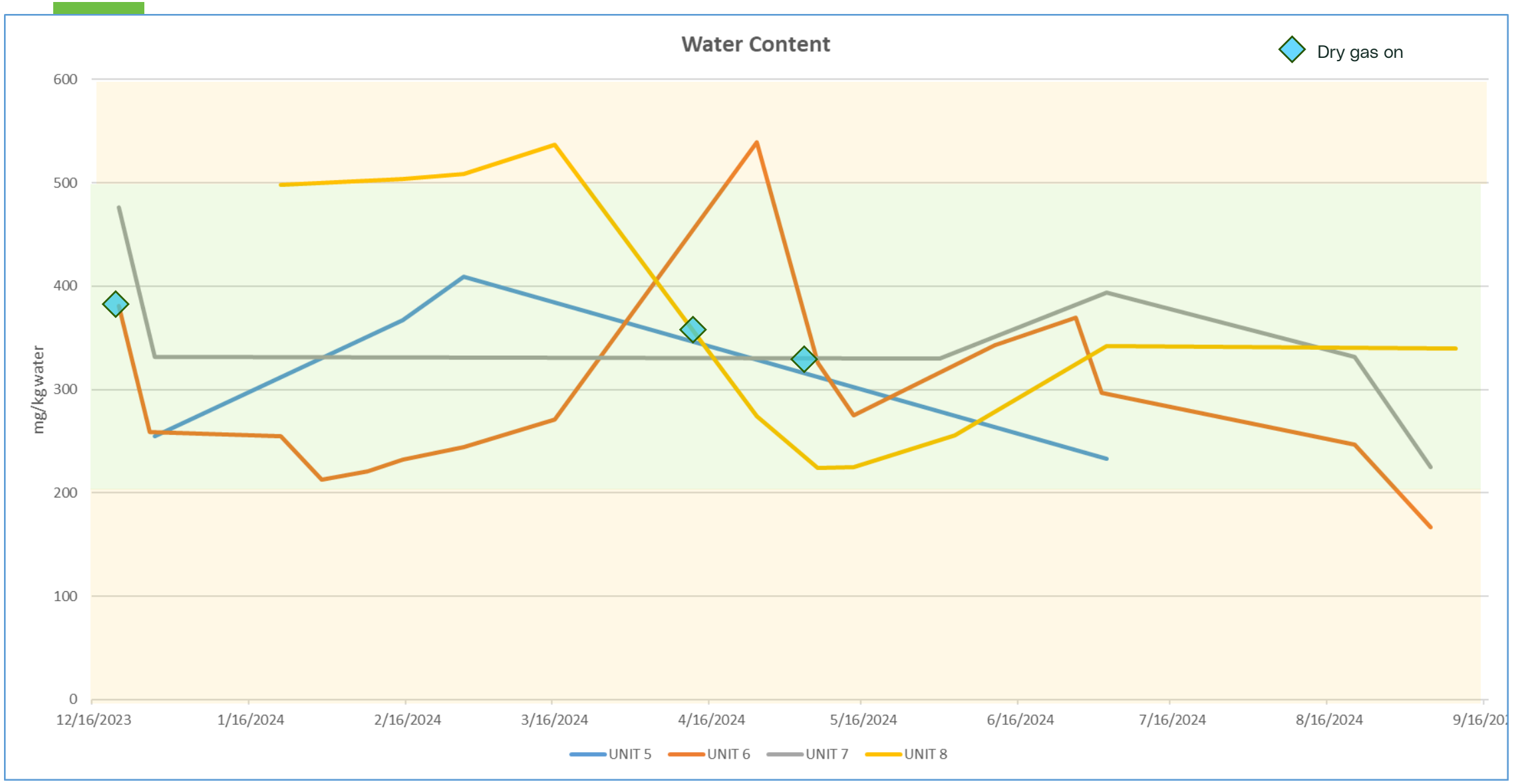
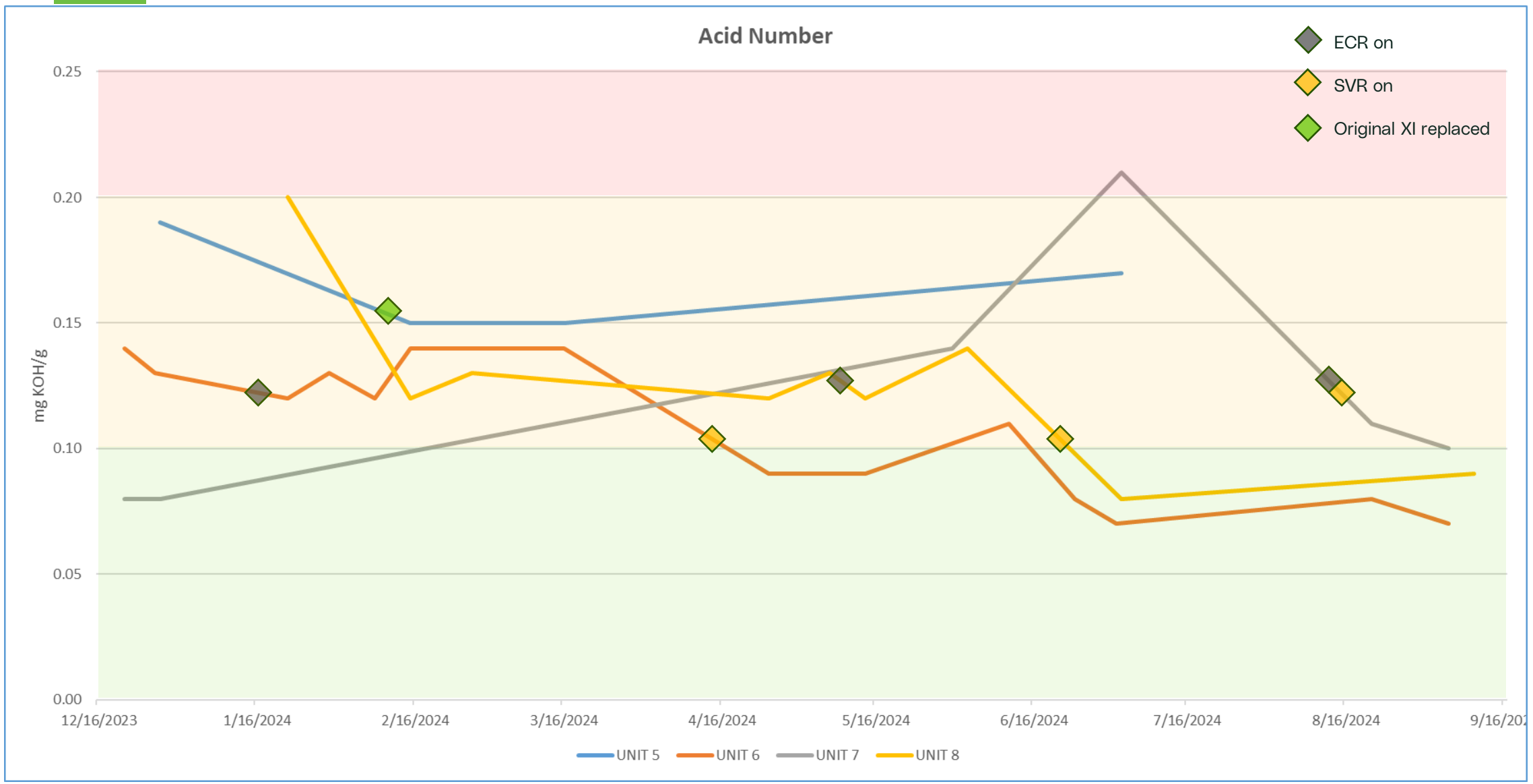
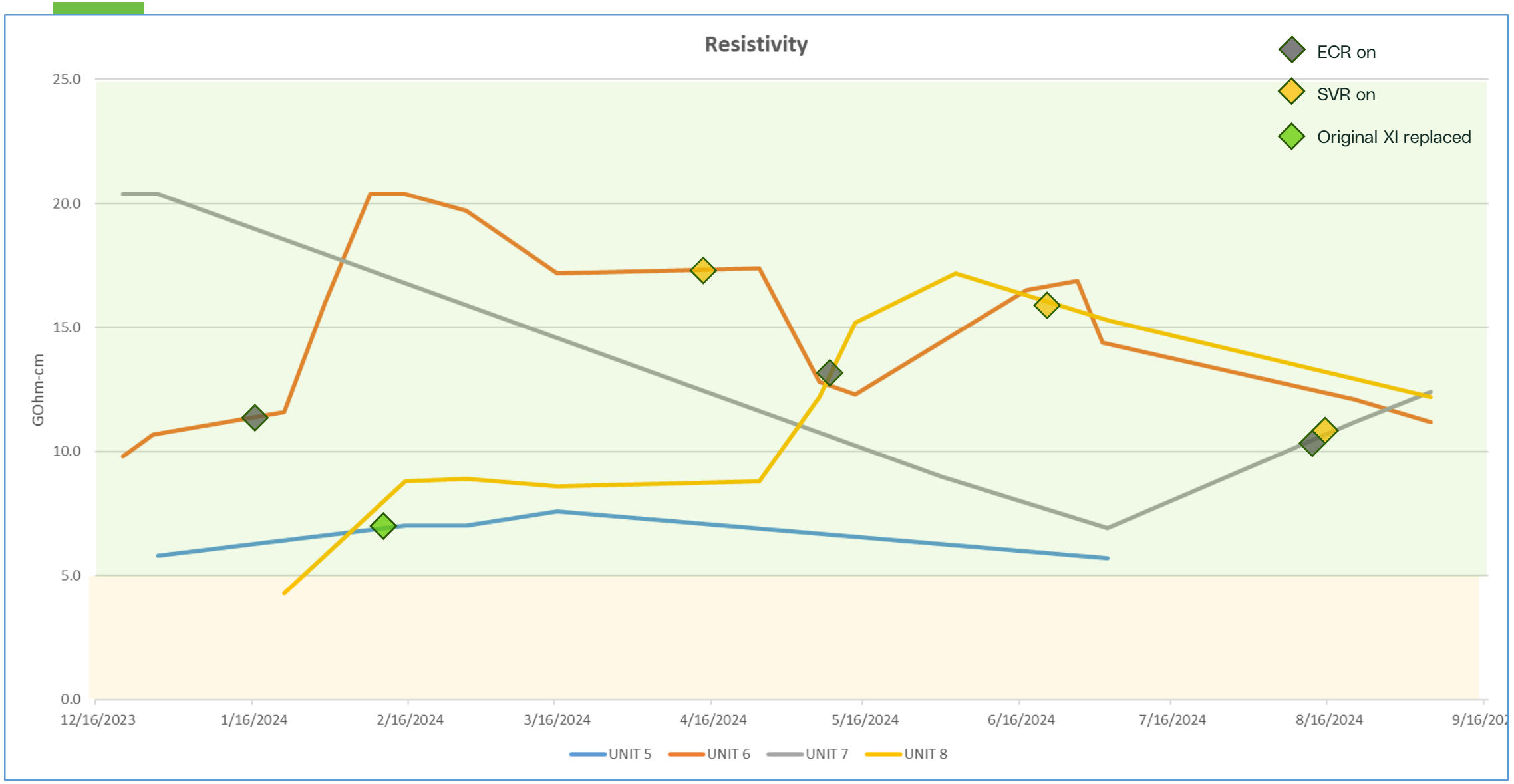
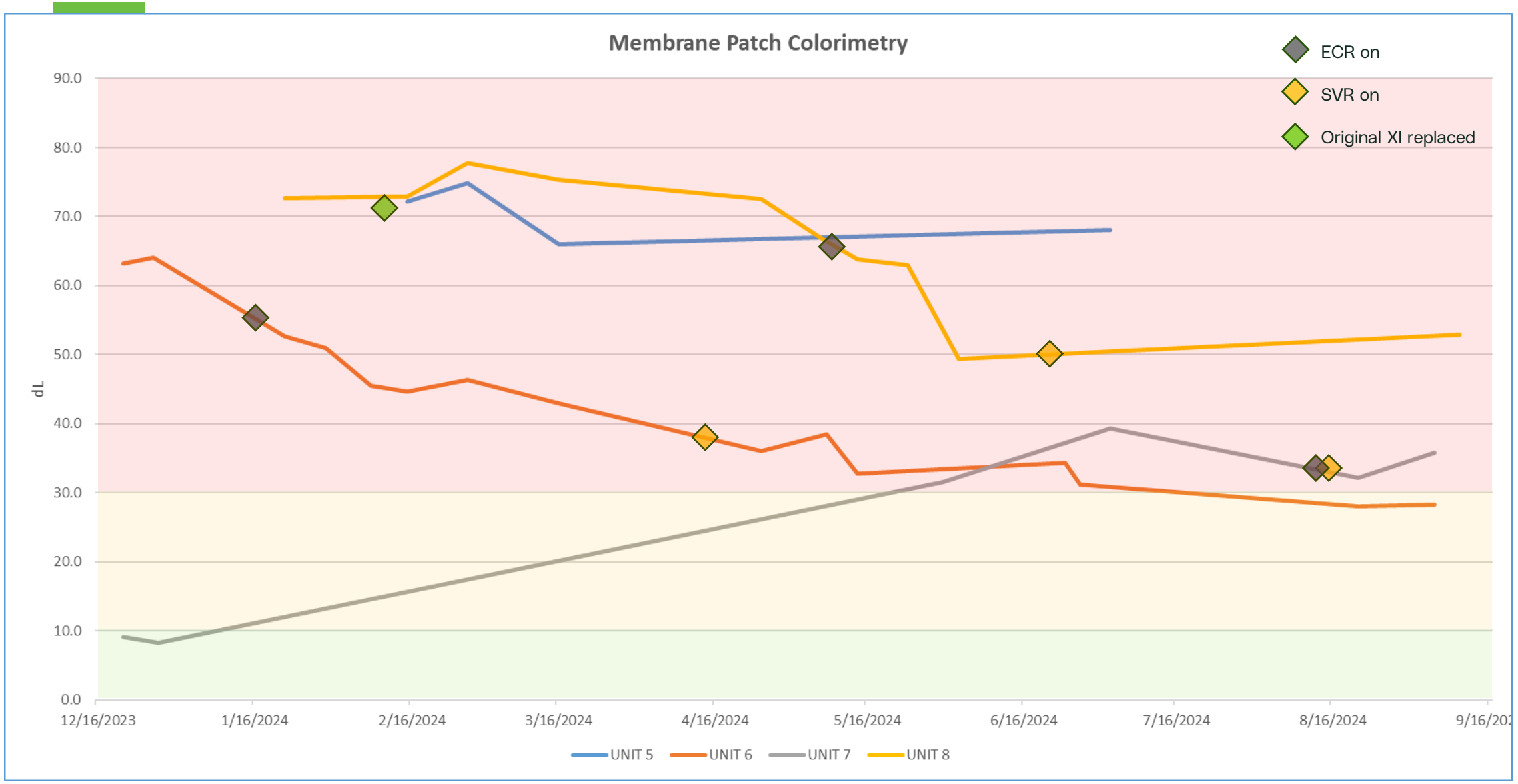
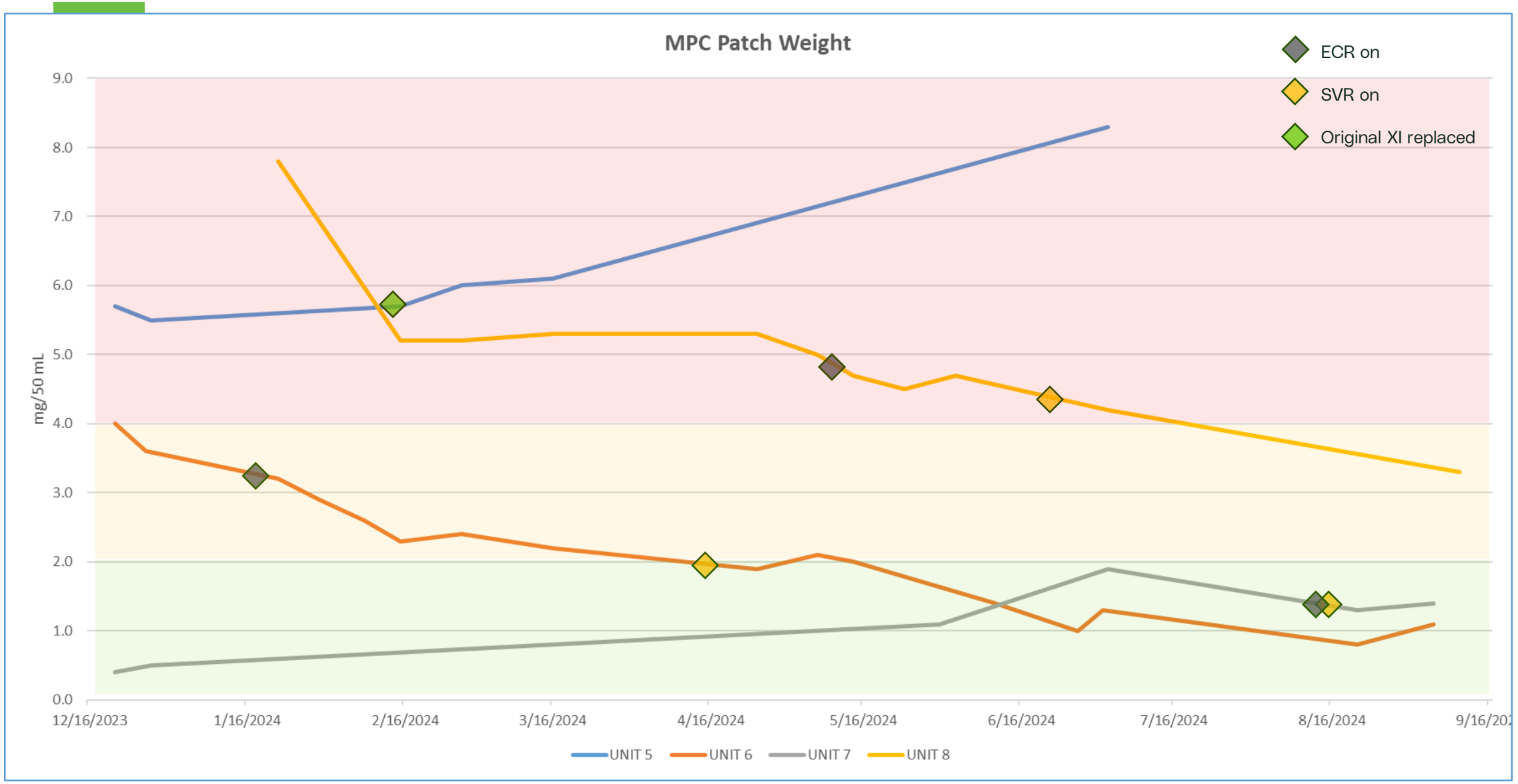
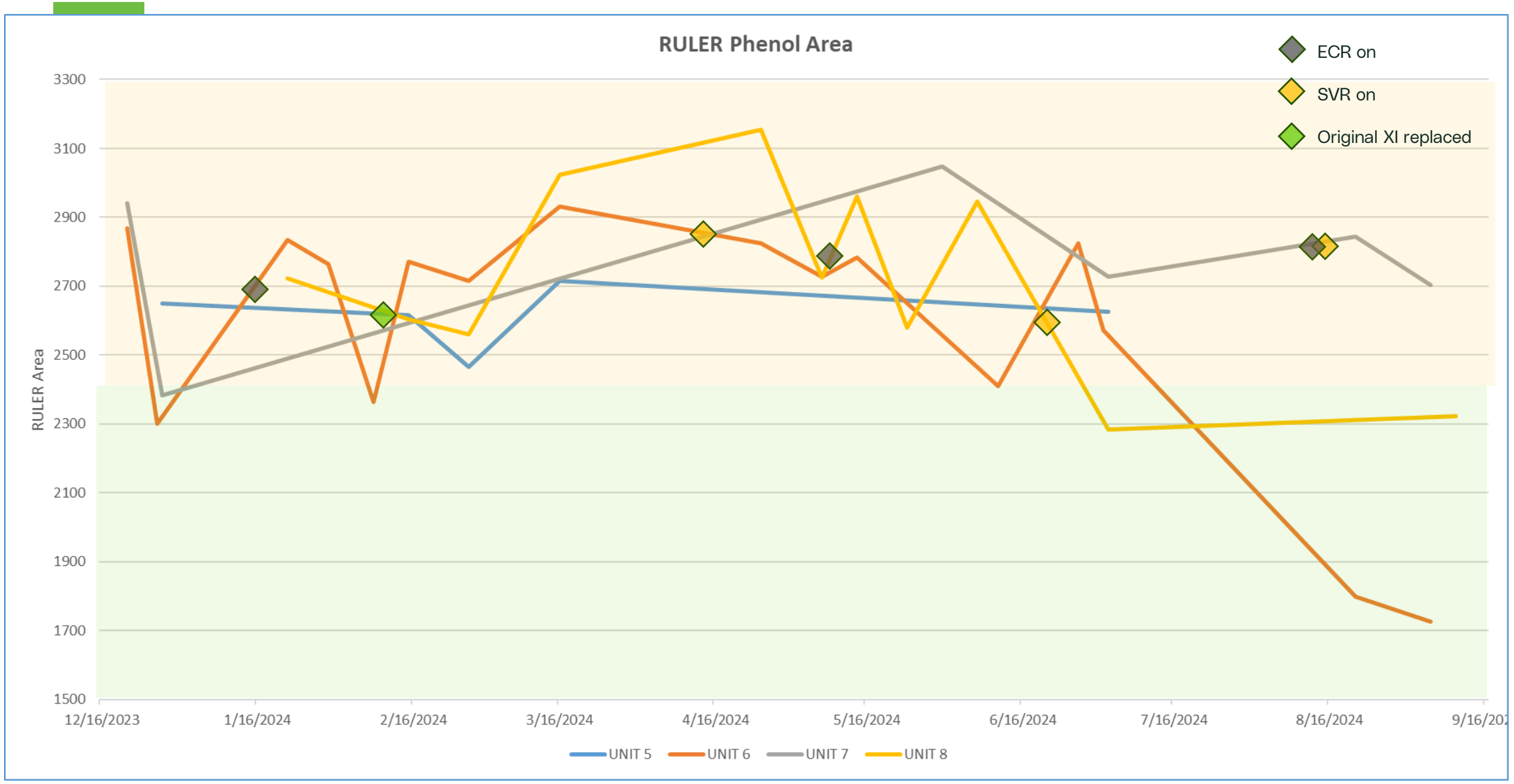

Water Content
Dry gas on
600
500
400
300
200
100
0
mg/kg water
12/16/2023
1/16/2024
2/16/2024
3/16/2024
4/16/2024
5/16/2024
6/16/2024
7/16/2024
8/16/2024
UNIT 5
UNIT 6
UNIT 7
UNIT 8

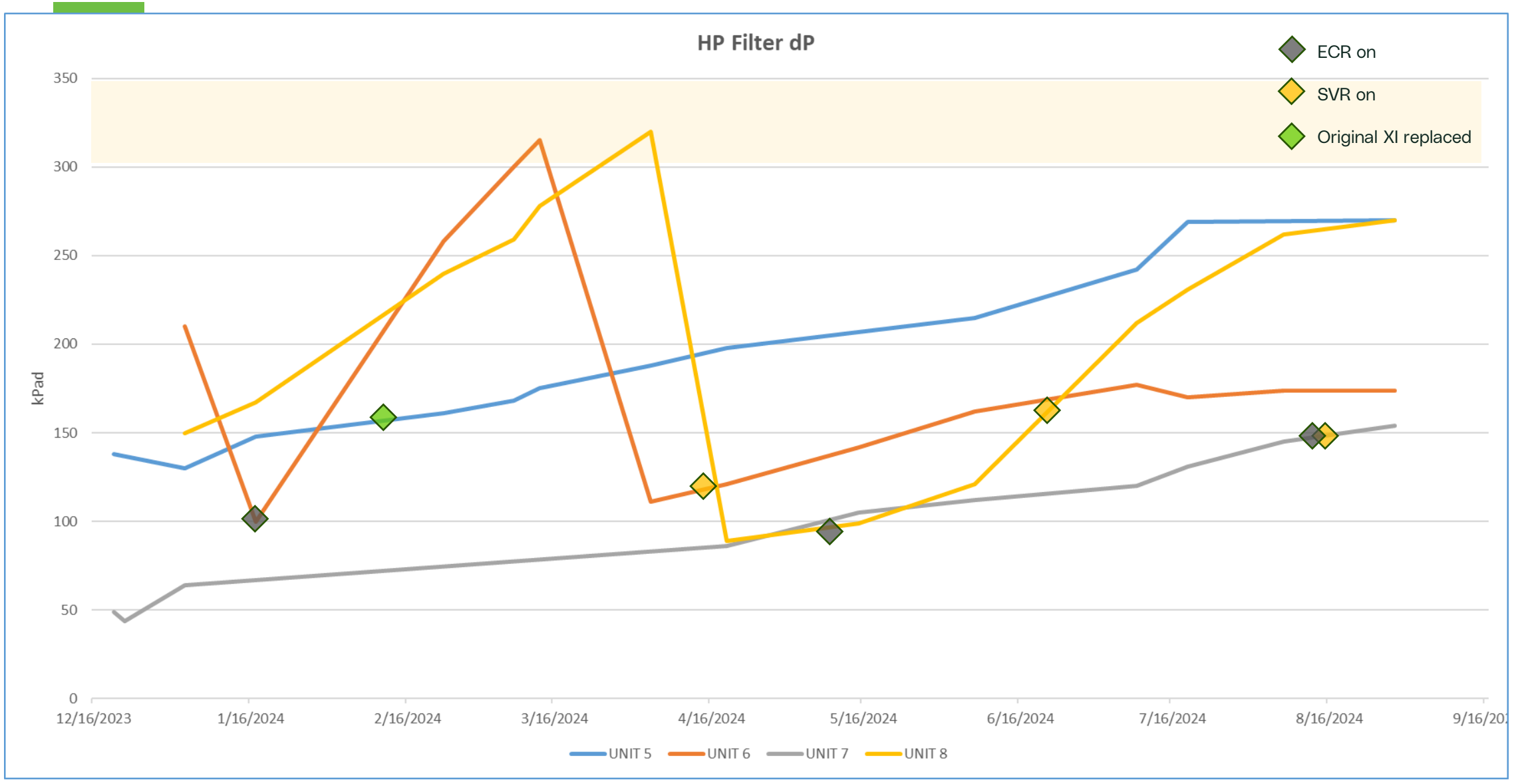

Acid Number
ECR on
SVR on
Original XI replaced
0.25
0.20
0.15
0.10
0.05
0.00
mg KOH/g
12/16/2023
1/16/2024
2/16/2024
3/16/2024
4/16/2024
5/16/2024
6/16/2024
7/16/2024
8/16/2024
UNIT 5
UNIT 6
UNIT 7
UNIT 8


Resistivity
ECR on
SVR on
Original XI replaced
25.0
20.0
15.0
10.0
5.0
0.0
GOhm-cm
12/16/2023
1/16/2024
2/16/2024
3/16/2024
4/16/2024
5/16/2024
6/16/2024
7/16/2024
8/16/2024
UNIT 5
UNIT 6
UNIT 7
UNIT 8


Membrane Patch Colorimetry
ECR on
SVR on
Original XI replaced
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
dL
12/16/2023
1/16/2024
2/16/2024
3/16/2024
4/16/2024
5/16/2024
6/16/2024
7/16/2024
8/16/2024
UNIT 5
UNIT 6
UNIT 7
UNIT 8


MPC Patch Weight
ECR on
SVR on
Original XI replaced
mg/50 mL
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
12/16/2023
1/16/2024
2/16/2024
3/16/2024
4/16/2024
5/16/2024
6/16/2024
7/16/2024
8/16/2024
UNIT 5
UNIT 6
UNIT 7
UNIT 8


RULER Phenol Area
ECR on
SVR on
Original XI replaced
RULER Area
3300
3100
2900
2700
2500
2300
2100
1900
1700
1500
12/16/2023
1/16/2024
2/16/2024
3/16/2024
4/16/2024
5/16/2024
6/16/2024
7/16/2024
8/16/2024
UNIT 5
UNIT 6
UNIT 7
UNIT 8


HP Filter dP
ECR on
SVR on
Original XI replaced
kPad
350
300
250
200
150
100
50
0
12/16/2023
1/16/2024
2/16/2024
3/16/2024
4/16/2024
5/16/2024
6/16/2024
7/16/2024
8/16/2024
UNIT 5
UNIT 6
UNIT 7
UNIT 8

Key Takeaways

- Overall good control of parameters of interest.
- Rapid MPC improvement for Unit 7 in 2023; not nearly as dramatic in 2024.
- No change seen in HP filter depletion rate.
- Challenges:
  - Commissioning requires close teamwork with vendor, project management, operations, chemistry, maintenance and engineering to achieve success.
  - Excessive downtime when filter canisters are changed.
  - Challenges to keep water content in the sweet spot due to frequent dry gas flow adjustments.
- Recommendations (to the vendor):
  - Add duplex SVR filters to allow for online canister changes and avoid excessive downtime
  - Automate water content measurement and dry gas flow control

Electrifying life

OPG