BASF/inge® dizzer® XL 0.9 MB 70 WT

UF Membrane Pilot Testing for

City of Ashland, OR

Pilot Report Final

October 6th – December 12th, 2017

Project	**Ashland**	Report No.	**H20I-01-2017**
Project No.	**-**	Date	**03/22/2018**
Customer	**City of Ashland, OR** **Keller Associates and HDR**	Reporting period	**10/06 – 12/12/2017**
		Pilot Unit	**H2OI UF pilot (extracted from container) using one dizzer® XL 0.9 MB 70 WT**
Contact person	**-**	Remarks	**Conclusion of pilot**
Report	**Joseph Kelly**		

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1. Executive Summary

The City of Ashland is in the process of preliminary design of a new water treatment plant (WTP) with full capacity in the range of 10 million gallons per day (MGD). The City is leaning favorably toward using a membrane filtration system in the new plant.

A pilot study was conducted from August through December 2017 to evaluate the performance of membrane systems for the treatment of source water from Reeder Reservoir and Talent Irrigation District (TID) and to refine the design parameters for a full-scale system.

The pilot program was segmented into three distinct Source Water Evaluations each for a 28-day duration. The three distinct evaluations were referred to as Design Run #1, #2, and #3 throughout the pilot program.

2. Introduction

The City of Ashland is in the process of preliminary design of a new water treatment plant (WTP) with full capacity in the range of 10 million gallons per day (MGD). The City is leaning favorably toward using a membrane filtration system in the new plant.

The City conducted a pilot test of three membrane filtration systems for approximately five months from late summer through early winter 2017. Performance during the pilot test and system cost will be evaluated to select the final membrane filtration system for installation in the new WTP (Project).

The three membrane filter manufacturers / systems which participated in pilot testing:

- Aqua-Aerobic, MultiBore C-Series ceramic membrane
- BASF/inge, H2O Innovation, dizzer® Multibore® UF membrane
- Pall Corporation, Asahi UNA-620A membrane

The pilot program was segmented into three distinct Source Water Evaluations each for a 28-day duration. The three distinct evaluations were referred to as Design Run #1, #2, and #3 throughout the pilot program. The city of Ashland and engineer have decided to use the pilot data obtained from the Reeder Reservoir source water evaluations as the basis for the full-scale design basis.

The source water for Design Run #1 originated from the Talent Irrigation District (TID). The City of Ashland draws water from the TID source in the summer if their primary source, the Reeder Reservoir becomes too low. The engineer decided to run this evaluation first, since the TID source water is more challenging to the WTP operation. The injection pump for the ACH injection was not operating in its automatic mode and therefore failed to inject the coagulant during Design Run #1. The engineer and City of Ashland decided to omit the results from Design Run #1.

The data from (Design Run #2) should be used for the WTP design basis for operation from October through May and (Design Run #3) for June through September.

In the following sections the results of Design Run #2 and Design Run #3 will be reviewed in detail.

3. Process Overview

The source water for design run #2 and design run #3 for the pilot program, originated from the Reeder Reservoir which is the primary water source the WTP draws from to provide the City Ashland with drinking water. As part of the pilot program coagulant, aluminum chlorohydrate (ACH), was continuously injected at a concentration of 8 ppmw (2 ppmw Al^{3+}) to the influent water piping common to all three UF pilots under evaluation. The ACH was injected upstream of the pilot units to provide adequate residence time for the injected coagulant. The influent piping formed a header which provided the influent source water for each of the three UF pilots. The H2OI/inge UF pilot was the last pilot on this influent header, which occasionally resulted in lower flow rate into the feed tank than the filtrate output.

UF Module dizzer® XL 0.9 MB 70

The inge® UF modules are designed as pressure-driven in-out configuration and equipped with the inge® Multibore® fibers (Figure 1). Pore size of the modified polyethersulfone (PESm) UF fibers is 20 nm. A more detailed description of the membrane module is provided in the following Table.

Parameter	Value
Nominal Membrane Classification (Microfiltration, Ultrafiltration)	Ultrafiltration
Module/Element Part #	XL 0.9 MB 70 WT
Fiber - Dimensions and Construction	
Nominal Pore Size	0.02 µm
Material (PVDF, PP, PES, etc. .)	PES modified
Surface Charge (Positive, Negative, Neutral)	negative
Surface Chemistry (Hydrophilic, Hydrophobic)	hydrophilic
ID	0.9 mm
OD	4.0 mm
Effective Length	1,720 mm (67.7 in)
Flow Path (Inside-Out; Outside-In)	Inside-Out
Type (Hollow Fiber, Multibore, Monolithic)	Multibore®
pH Tolerance	1-13
Maximum Chlorine Tolerance	250,000 mg/l x hours
Temperature Tolerance	0°C – 40°C (32°F – 104°F)
Module/Element – Dimensions and Construction	
Fibers (#/module/element)	2,210
Filter Area	70 m² (753 ft^2)
Potting Material	Epoxy
Casing Material	PVC-U
Dimension (L, W, D)	L = 1,720 mm (67.7 in) D = 250 mm (9.875 in)
ANSI/NSF Standard 61 and 419 certifications	Yes

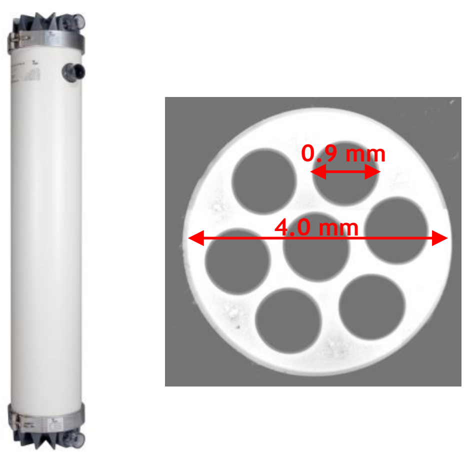


Figure 1: UF Module dizzer® XL 0.9 MB 70; Multibore® MB 0.9 fiber

Standard inge® UF operation

Filtration operation using inge® UF modules can be broken down in 3 main process components:

1. **Filtration mode:** Operation in "dead end" mode at constant filtration flux rate. During the filtration time, a fouling layer consisting of the rejected particles is building up on the membrane surface and causing an increase of transmembrane pressure (TMP) on the membrane surface. Depending on the feed water quality a **backwash** will be released after the defined filtration time has expired.

2. **Backwash mode:** 30 – 60 s membrane flux rate of 135 GFD during backwash. The strong backwash at high velocity ensures a high efficient removal of particles and a stable operation at low pressure.

3. **Chemical Enhanced Backwash (CEB) mode:** Chemicals are injected into the backwash water during the CEB cycle. Alkaline agents (pH > 12) are used for cleaning of residual organic fouling layers while acidic agents (pH < 2.5) are deployed to clean inorganic scale formations. Alternatively, oxidizing additives can be injected (e.g. NaOCl) to disinfect the UF membrane. Optimized CEB protocols help facilitate long term stable filtration performance.

   <u>**Note**</u>: The high pH and low pH solutions will neutralize each other resulting in a solution with pH between 8 and 9 which may be disposed without further neutralization

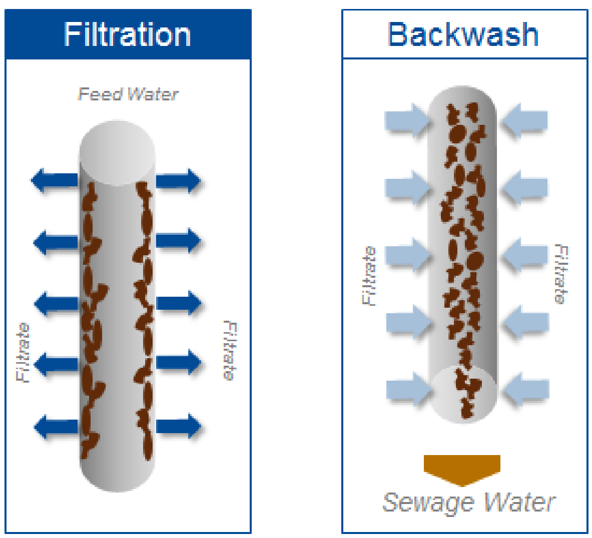


Figure 2: Dead-End In-out Filtration and Backwash

H2OI/inge pilot

The UF pilot uses an Amiad TAF stye 300-mesh automatic strainer backwash (SBW) to protect the UF membrane from potentially damaging large debris. The water enters the inner area of the screen-cylinder through the inlet and flows throughout the 300-mesh to the outlet. The dirt particles are trapped on the inner screen surface and form a "filtration cake" that causes a differential pressure across the screen. During the self-cleaning process, while filtered water continues to flow, the strainer exhaust valve is opened, and the drive unit spirals the suction Scanner back and forth. The spiral rotation of the suction scanner nozzles across the inner surface of the screen "vacuums" the filtration cake out the exhaust valve.

The effluent of the SBW is collected in a 1000-gallon feed tank. The UF pilot is a system comprised of pumps, valves and instrumentation. The system uses PID loops where the instrumentation measures an input or process variable (PV) and compares that to the entered process set-point (SP) which results in control variable (CV) as an output. The output of the feed pump which provided flow to the UF filter is on a PID loop. The output of the pump is variable permitting the membrane flux rate to be held constant despite the change to the measured process variable.

Due to technical limitations of the pilot plant, a 70 m² Multibore® 0.9 mm UF filter was utilized for the pilot study. An 80 m² UF filter is available for full scale operation.

The UF filter operates different sequences to verify membrane integrity, remove foulants from the membrane and produce high quality filtrate. These sequences are described in detail in the inge® Operations Manual.

The filtrate from the UF pilot fills a filtrate/backwash tank and the tank overflow then provides high quality filtrate suitable for storage or distribution.

A backwash sequence is initiated after a filtrate sequence where UF filtrate is pumped through the UF filter in the reverse direction. The reverse flowrate is set to achieve a membrane flux rate of 135 GFD during the backwash sequence. The discharge is first directed through the bottom drain port for 20 seconds and then the upper drain port for 20 seconds. The reverse flow dislodges accumulated foulant from the feed side of the filter which restores membrane permeability for the subsequent filtrate sequence.

The benefit of the increased permeability is balanced against the cost of the consumed filtrate water. Percent recovery is equal to the usable filtrate volume out/influent volume in. Percent Recovery is one measure used to determine the optimal filter process set-points.

Transmembrane Pressure (TMP)

$$TMP = P_f - P_p$$

Where: $TMP = Transmembrane\ Pressure\ (psi)$

$P_f = Feed\ Pressure\ (psi)$

$P_p = Filtrate\ Pressure\ (psi)$

The feed and filtrate pressure are evaluated at the same elevation datum.

Membrane Flux:

$$J_T = \frac{Q_{filtrate}}{(A_{filter} \times Time)}$$

Where: $J_T = \ Membrane\ Flux\ at\ Temperature\ (GFD)$

$Q_{filtrate} = Filtrate\ Flowrate\ (gpm)$

$A_{filter} = Surface\ Area\ of\ Filter\ Membrance\ (ft^2)$

$Time = Minutes\ in\ a\ Day\ (min)$

Permeability (Specific Flux):

$$M_T = \frac{J_T}{TMP}$$

Where: $M_T = Specific\ Flux\ at\ Temperature\ \left(\frac{GFD}{psi}\right)$ – *also called permeability*

$J_T = \ Membrane\ Flux\ at\ Temperature\ (GFD)$

$TMP = Transmembrane\ Pressure\ (psi)$

Recovery:

$$R = \frac{Q_p}{Q_f}$$

Where: R = Recovery (%)

$Q_p = Net\ Filtrate\ Produced\ (gallons)$

$Q_f = Total\ Feed\ to\ the\ Membrane\ System\ (gallons)$

4. Design Run #2 Setpoints

Design Run #2: Reeder Reservoir Source Water Evaluation with moderate flux rates, maintenance cleans not more frequent than every 24 hours (28 days of continuous operation) occurred from 8:00 AM on Friday October 6th, 2017 until 8:00 AM on Saturday November 4th, 2017.

The following parameters were used to evaluate the ultrafiltration process:

Set points listed below locked in for week #2 through week #4

Tuesday October 17th at 8:00 AM PST is the official time which SPs may not be altered.

- Filtrate flow rate = 28.8 gpm (55 GFD)
- Duration of Filtrate Sequence = 40 minutes

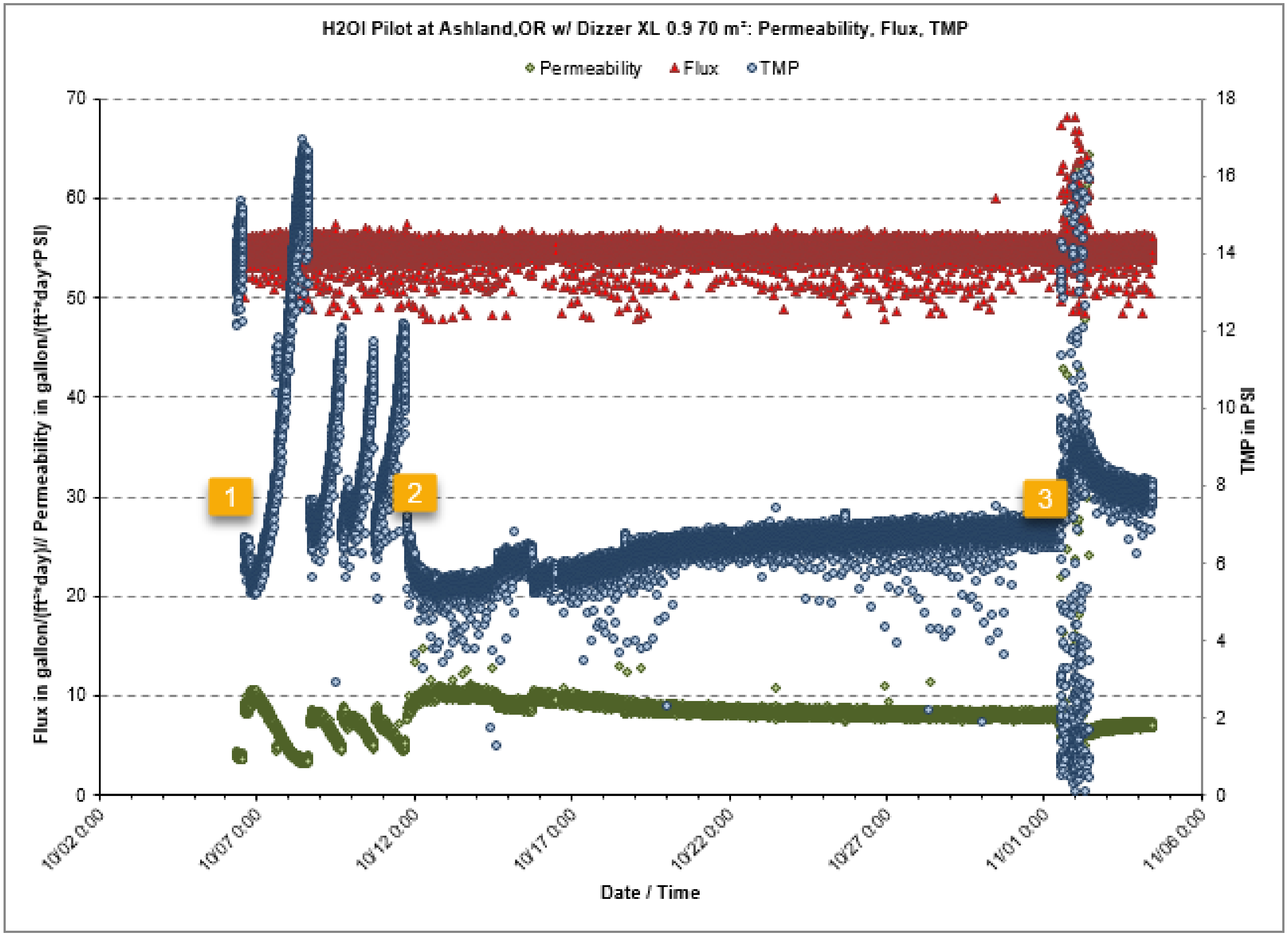
- Duration of Backwash Sequence = 40 seconds
- BW Flowrate = 71 gpm (note target is set at 73 to maintain actual 71 gpm)

- Maintenance Clean (MC) occurs twice weekly (2 occurences / week)
- MC consists of:
  - (1) Base cleaning with NaOH at pH of 12.2
  - 15 minutes of recirculation on the feed side
  - 15 minutes of soak time
  - 90 second MC rinse
  - (1) Acid cleaning with Sulfuric acid at pH 2.4
  - 15 minutes of recirculation on the feed side
  - 15 minutes of soak time
  - 90 second MC rinse

- Membrance Integrity Test occurs once per week (1 occurrence / 7 days)
- MIT has a total of 15 minute sequence duration (10 minute pressure hold/decay test @ 14.5 PSI, max delta p = 0.15 PSI/min)

- Resulting Percent Recovery 95.6%

4.1. Design Run #2 Ashland Data-Plot Permeability, Flux, and TMP from 10/06 – 11/04/17 (Figure #1)



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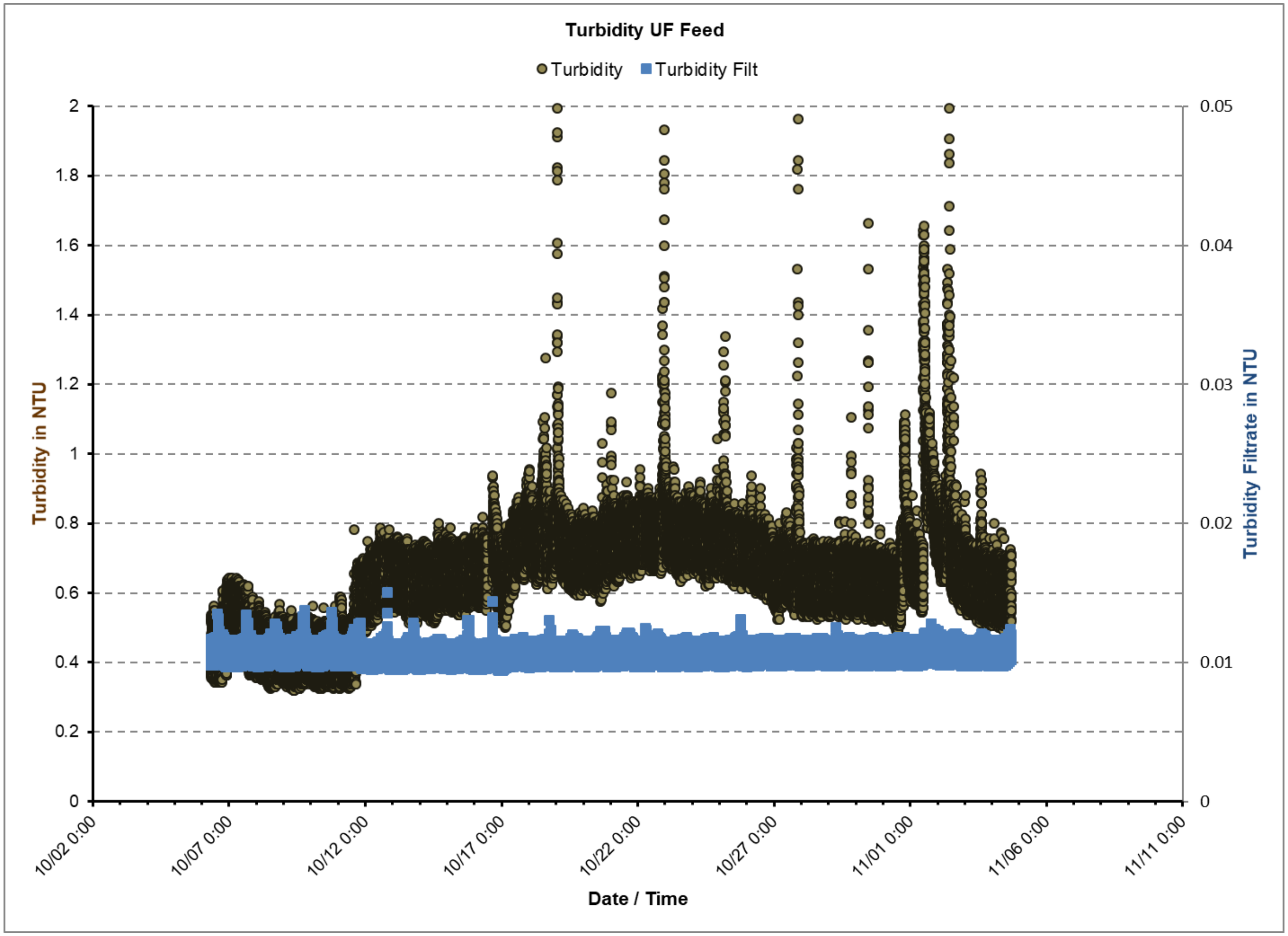
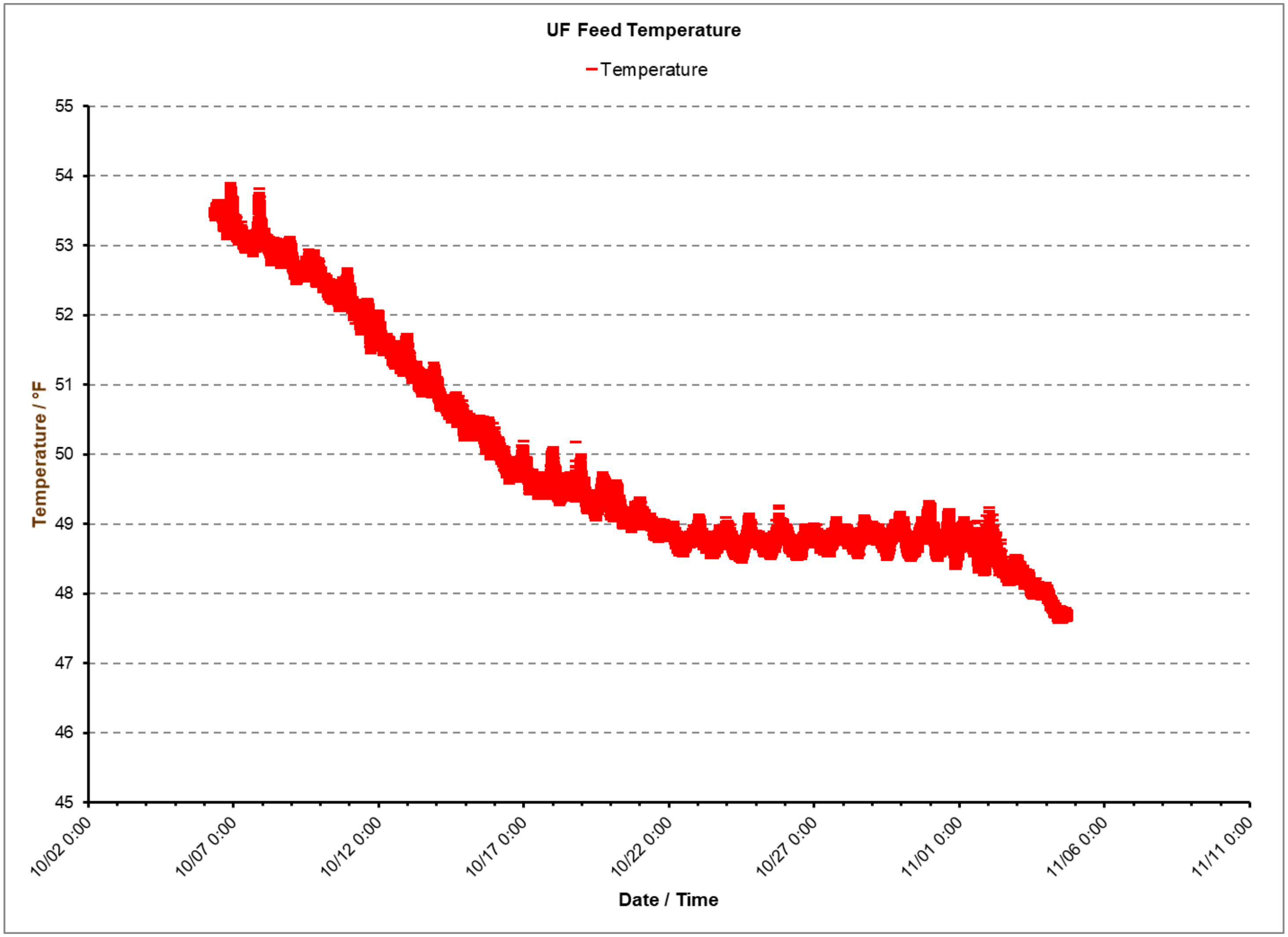
heart of pure water

4.2. Design Run #2 Ashland Turbidity Data-Plot from 10/06 – 11/04/17 (Figure #2)

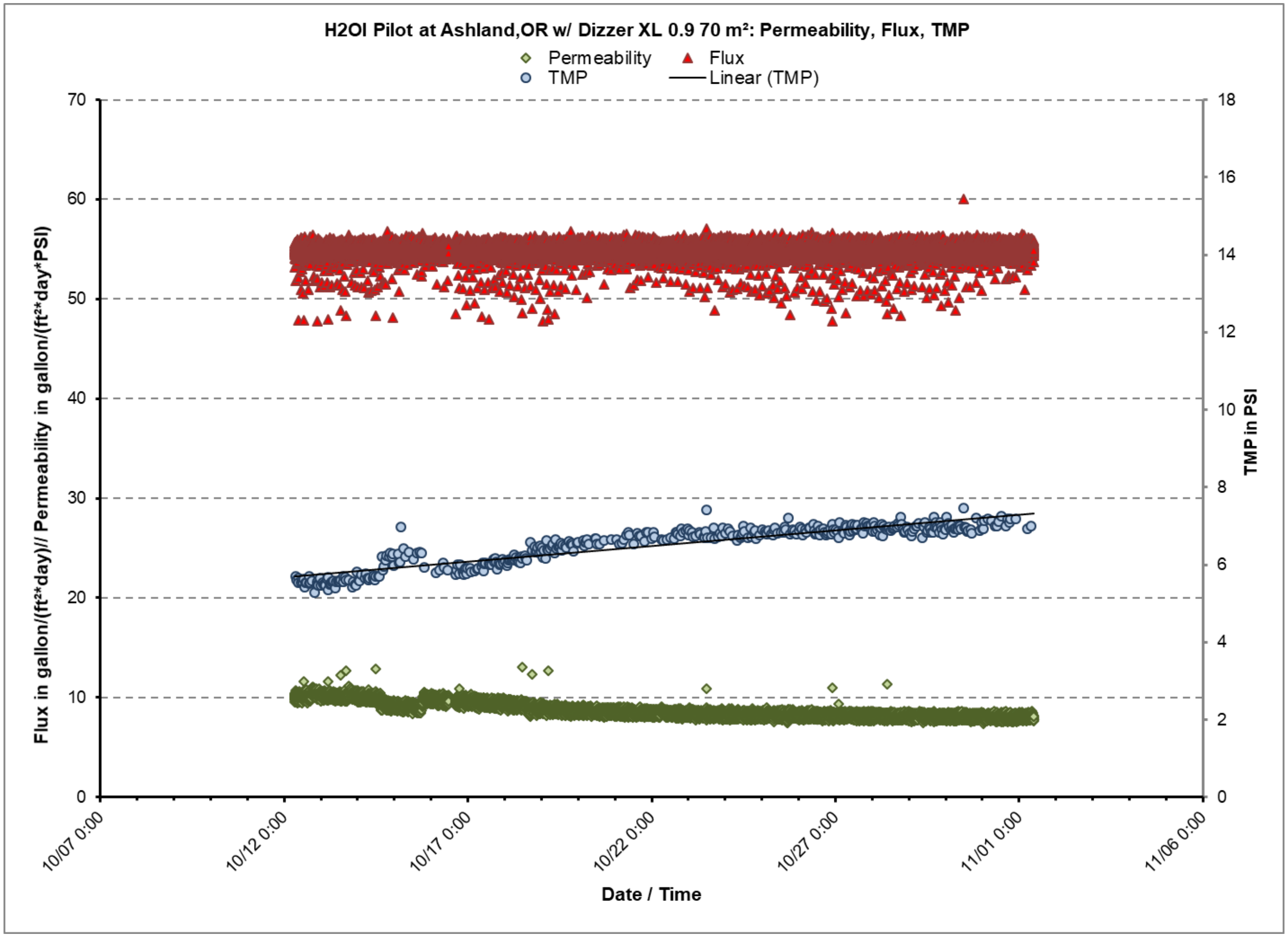


4.3. Design Run #2 Ashland Water Temperature (^oF) from 10/06 – 11/04/17 (Figure #3)



We create chemistry

4.4. Design Run #2 Ashland Data-Plot of TMP prior to BW from 10/12 – 11/01/17 (Figure #4)



5. Design Run #2 Statistics from 10/06 – 11/04/17 (Table #1)

	Min	Median	Average	Max	Std. Dev
Filtrate Flow (gpm)	25.00	28.78	28.84	34.98	0.73
Temperature (°F)	47.59	49.16	50.07	54.79	1.80
Feed Pressure (psi)	3.31	11.81	12.25	22.01	1.84
Filtrate Pressure (psi)	2.98	5.11	5.11	8.71	0.15
TMP Post BW (psi)	1.63	7.46	8.14	16.59	2.49
TMP Pre BW (psi)	5.29	8.03	9.02	16.71	2.86
Flux (GFD)	47.78	55.00	55.12	66.85	1.40
Temperature (°C)	8.66	9.54	10.04	12.66	1.00
TCF @20°C	1.22	1.34	1.32	1.37	0.04
TMP @20°C (psi)	0.23	4.99	5.44	13.51	1.50
Normalized Flux @20°C C (GFD)	58.79	73.15	72.54	90.89	2.71
Permeability @20°C (GFD/psi)	4.06	11.02	10.66	208.94	2.80
Feed Turbidity (NTU)	0.32	0.66	0.65	3.19	0.15
Filtrate Turbidity (NTU)	0.009	0.011	0.011	0.015	0.001

Design Run #2 Statistics from 10/12 – 11/01/17 (Table #1.1)

	Min	Median	Average	Max	Std. Dev
Filtrate Flow (gpm)	25.00	28.78	28.76	31.41	0.32
Temperature (°F)	48.36	48.96	49.34	51.74	0.80
Feed Pressure (psi)	7.65	11.65	11.48	13.30	0.52
Filtrate Pressure (psi)	3.87	5.12	5.12	5.82	0.09
TMP Post BW (psi)	4.95	6.35	6.13	6.83	0.49
TMP Pre BW (psi)	5.29	6.73	6.50	7.45	0.52
Flux (GFD)	47.78	54.99	54.96	60.02	0.61
Temperature (°C)	9.09	9.42	9.63	10.97	0.44
TCF @20°C	1.28	1.34	1.33	1.35	0.02
TMP @20°C (psi)	2.80	4.87	4.78	5.57	0.33
Normalized Flux @20°C (GFD)	61.57	73.41	73.17	80.67	1.25
Permeability @20°C (GFD/psi)	9.91	11.29	11.56	17.36	0.82
Feed Turbidity (NTU)	0.49	0.70	0.70	3.19	0.11
Filtrate Turbidity (NTU)	0.009	0.011	0.011	0.015	0.001

The data table above excludes the process distrubutions, it consists of the stable operation illustrated in Figure #1 between Tag #2 and Tag # 3.

6. Discussion of Results (Design Run #2)

Figure #1 provides an illustration of the UF filter performance for the duration of design run #2. Tag #1 illustrates the UF performance prior to the 8 ppmw ACH injection to the influent water, the TMP increased rapily over the course of each day with excellent recovery after each maintenace clean. Tag #2 marks a distinct positive change in UF filter performance occured on 10/11, which was when the ACH injection began.

The coagulation supports fouling control from organic molecules and colloids. The TMP in between MC cycles most likely related to remaining organics and aluminum.

The UF Filter performance was very stable from 10/12 until 11/01 when something caused an increase to the rate of TMP rise, marked with Tag #3 on Figure #1. One possible explaination could be the loss of coagulant addition which resulted in increased fouling and TMP as the fouling and TMP continued to be high after the event ended. However, operating the UF membrane with and without coagulation did not affect the filtrate turbidity at all.

Figure #4 is a plot of the TMP at the end of each filtrate cycle. This illustrates the highest TMP for each filtration sequence between 10/12 and 11/01. During this 20-day run, the lowest TMP (end cycle) was 5.30 psi and the highest TMP (end cycle) was 7.45 psi resulting in a rate of change of 0.11 psi/day. This rate of TMP increase (end of cycle) can be maintained despite periodic changes to the influent water quality with the use of the sulfuric acid MC. The use of oxidative chemical like NaOCl was not required to recover the membrane permeability.

The data from (Design Run #2) should be used for the WTP design basis for operation from October through May. October 1st to May 31st would be approximately 243 days. If the turbidity and TOC drastically increase with rain storms, the CIP frequency would be higher that the projected 4-month frequency based on the 0.11 psi/day increase.

For the water treatment plant to operate with natural inlet head pressure alone, it is desired to operate the membrane system below a maximum TMP of 20 psi. At a flux rate of 55 GFD, CIP frequency of once every 4 months would maintain a maximum TMP range from 5.5 psi to 18.5 psi between the start of October and the end of May based on the TMP increase of 0.11 psi/day experienced during Design Run #2. Allowing for 2 psi of pressure loss through the influent SBW units the entire UF system could be operated with the available pressure head to the WTP. During stormy events where the WQ can worsen, the CIP frequency may be increased from a projected 4 months to every month instead. During colder months, the flux may be derated by using the TCF to maintain the same TMP.

7. Design Run #3 Setpoints

For this run, Reeder Reservoir Source Water was evaluated with aggressive flux rates, more frequent MC but not more frequent than every 24 hours (28 days of continuous operation) occurred from 8:00 AM on Friday November 14th, 2017 until 8:00 AM on Saturday December 12th, 2017.

Set points listed below remained constant for November 14th to Dec 1st . Setpoints were changed Dec 1st and maintained until the conclusion of the design run.

Tuesday November 14th at 8:00 AM PST is the official time which SPs may not be altered.

- Filtrate flow rate = 39.3 gpm (75 GFD)
- Duration of Filtrate Sequence = 35 minutes

- Duration of Backwash Sequence = 40 seconds
- BW Flowrate = 71 gpm (note target is set at 73 to maintain actual 71 gpm)

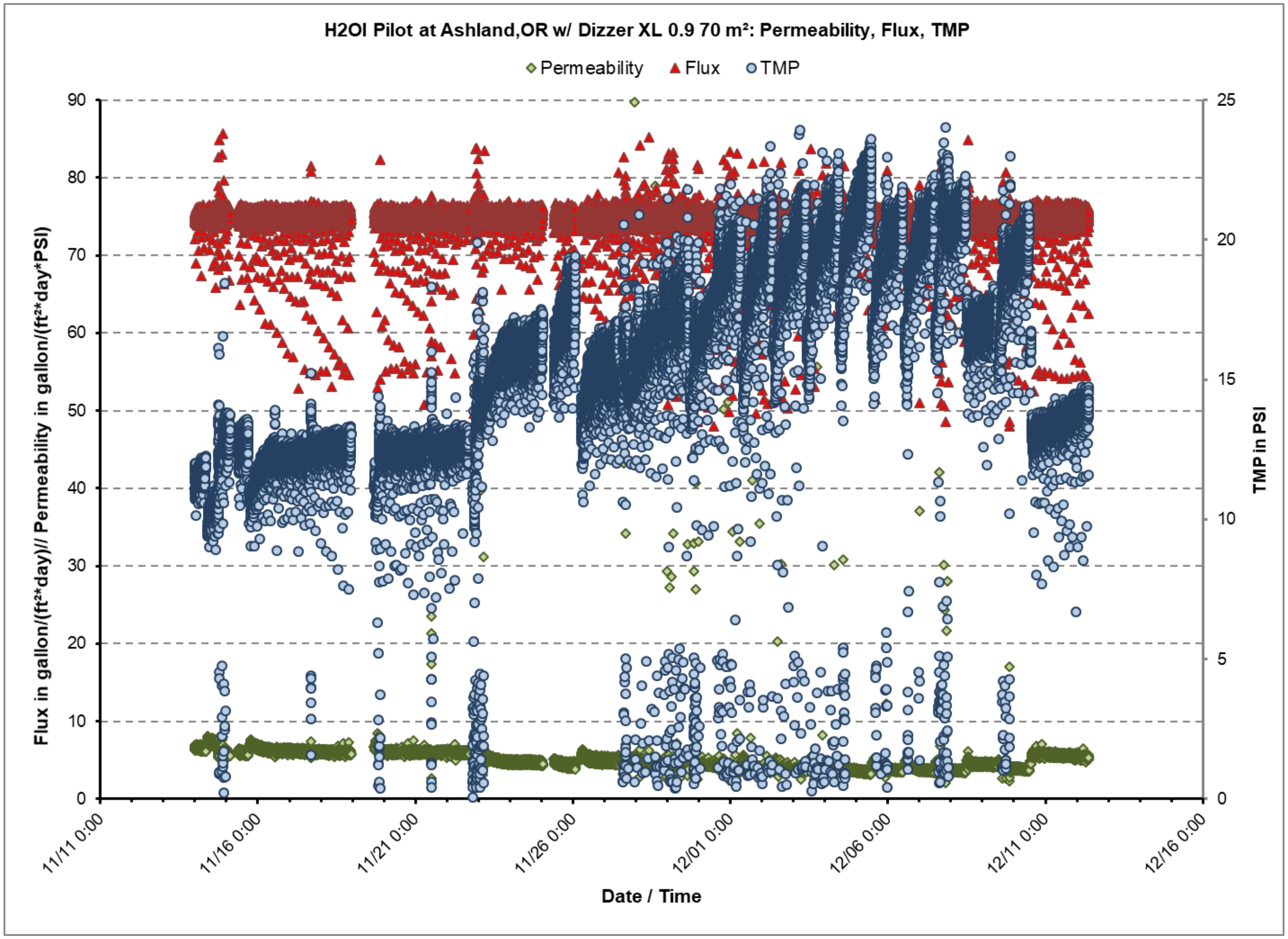
- Maintenance Clean (MC) occurs twice weekly (2 occurences / week)
- MC consists of:
  - (1) Base cleaning with NaOH at pH of 12.2
  - 15 minutes of recirculation on the feed side
  - 15 minutes of soak time
  - 90 second MC rinse
  - (1) Acid cleaning with Sulfuric acid at pH 2.4
  - 15 minutes of recirculation on the feed side
  - 15 minutes of soak time
  - 90 second MC rinse

- The calculated recovery is 96.4%

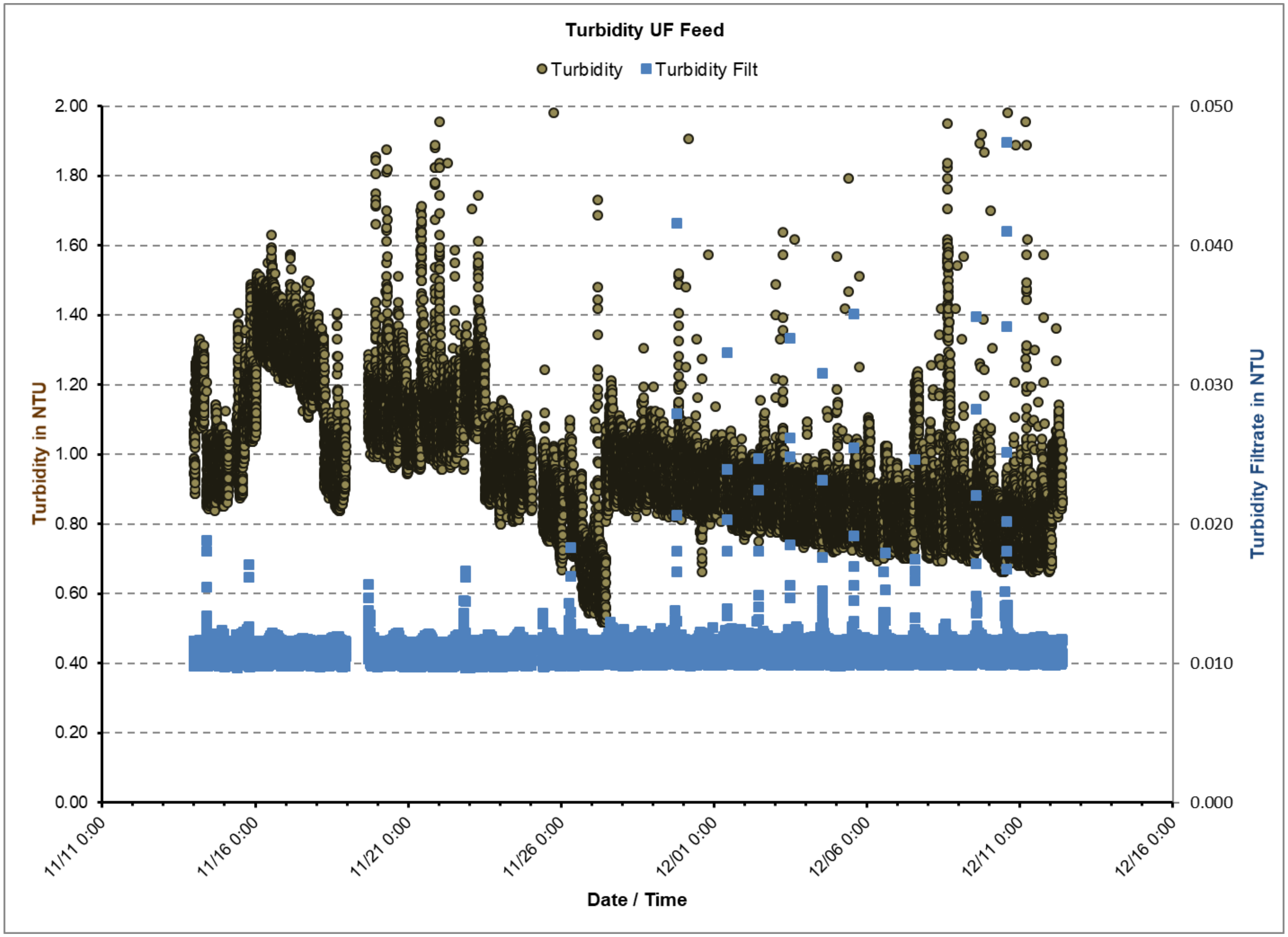
On the morning of Dec 1st the MC frequency was changed from twice weekly to three times weekly to keep the TMP below 20 psi which we believed is the limiting factor for the pressure available for the full-scale plant.

On the afternoon of Dec 1st the MC frequency was changed from 3x weekly to daily, again to keeping the TMP below the 20-psi limit.

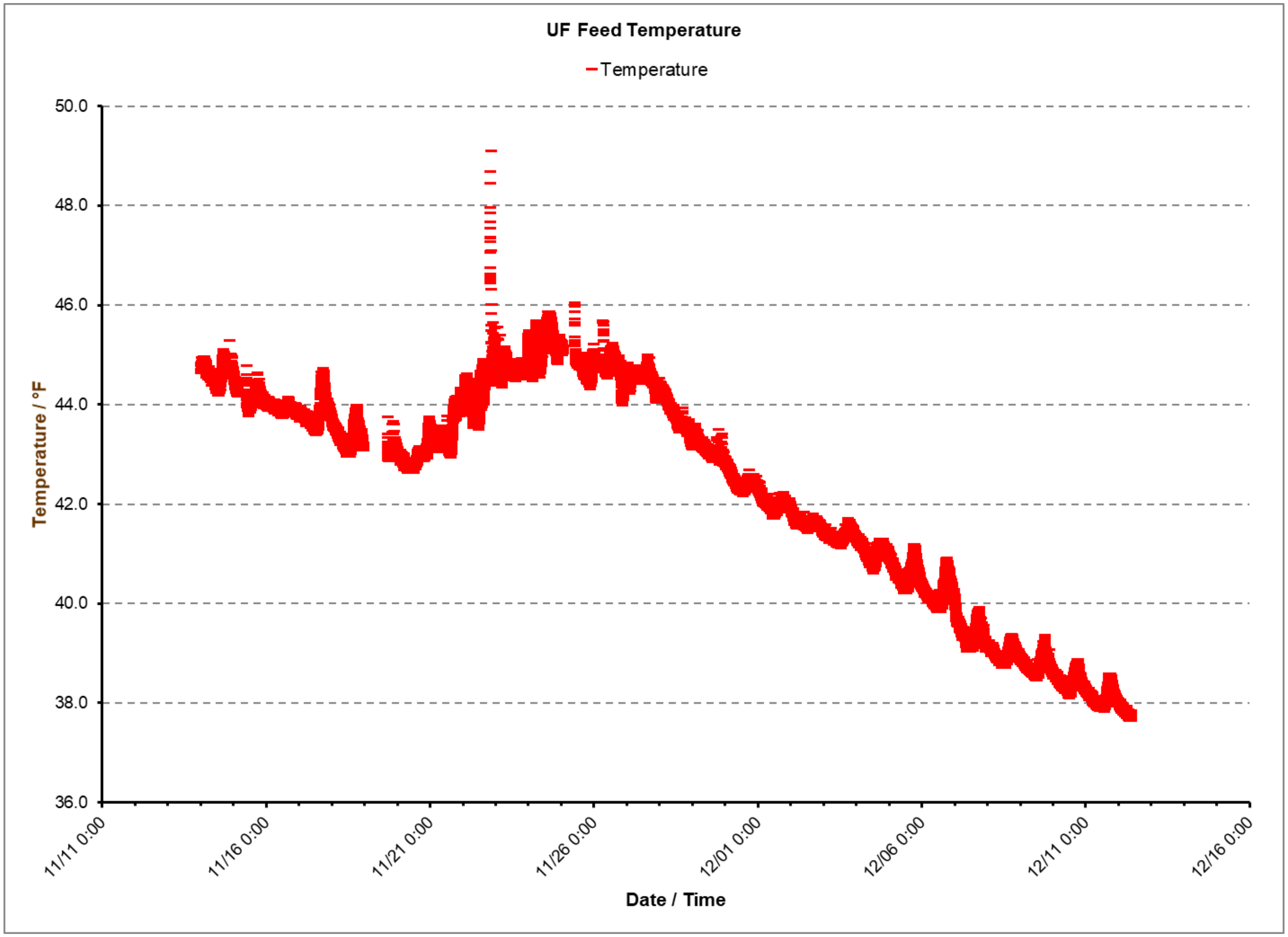
7.1. Design Run #3 Ashland Data-Plot Permeability, Flux, and TMP from 11/14 – 12/12/17 (Figure #5)



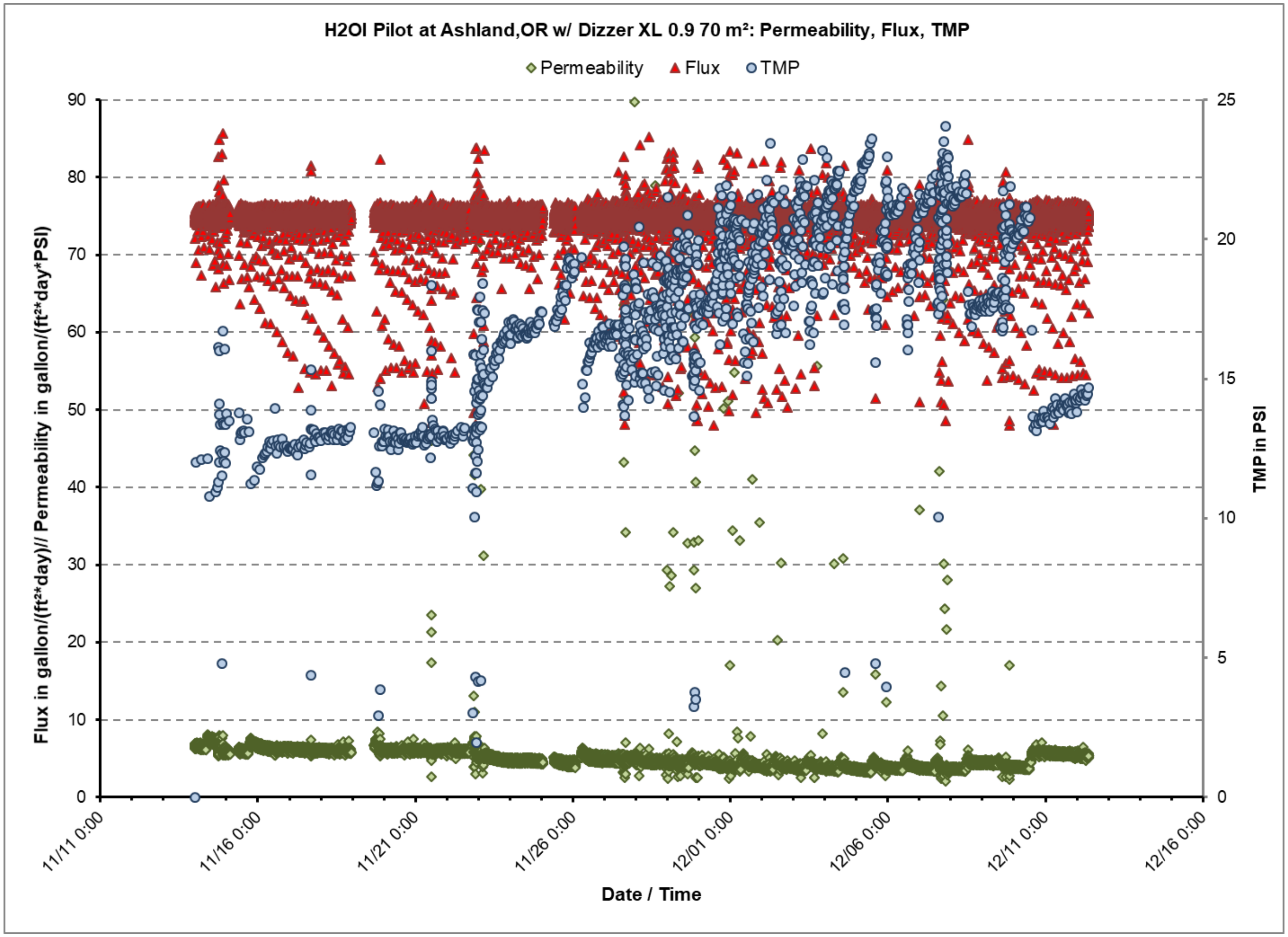
7.2. Design Run #3 Ashland Feed & Filtrate Turbidity Data-Plot from 11/14 – 12/12/17 (Figure #6)



7.3. Design Run #3 Ashland Water Temperature (^{o}F) from 11/14 – 12/12/17 (Figure #7)



7.4. Design Run #3 Ashland Data-Plot of TMP prior to BW from 11/14 – 12/12/17 (Figure #8)



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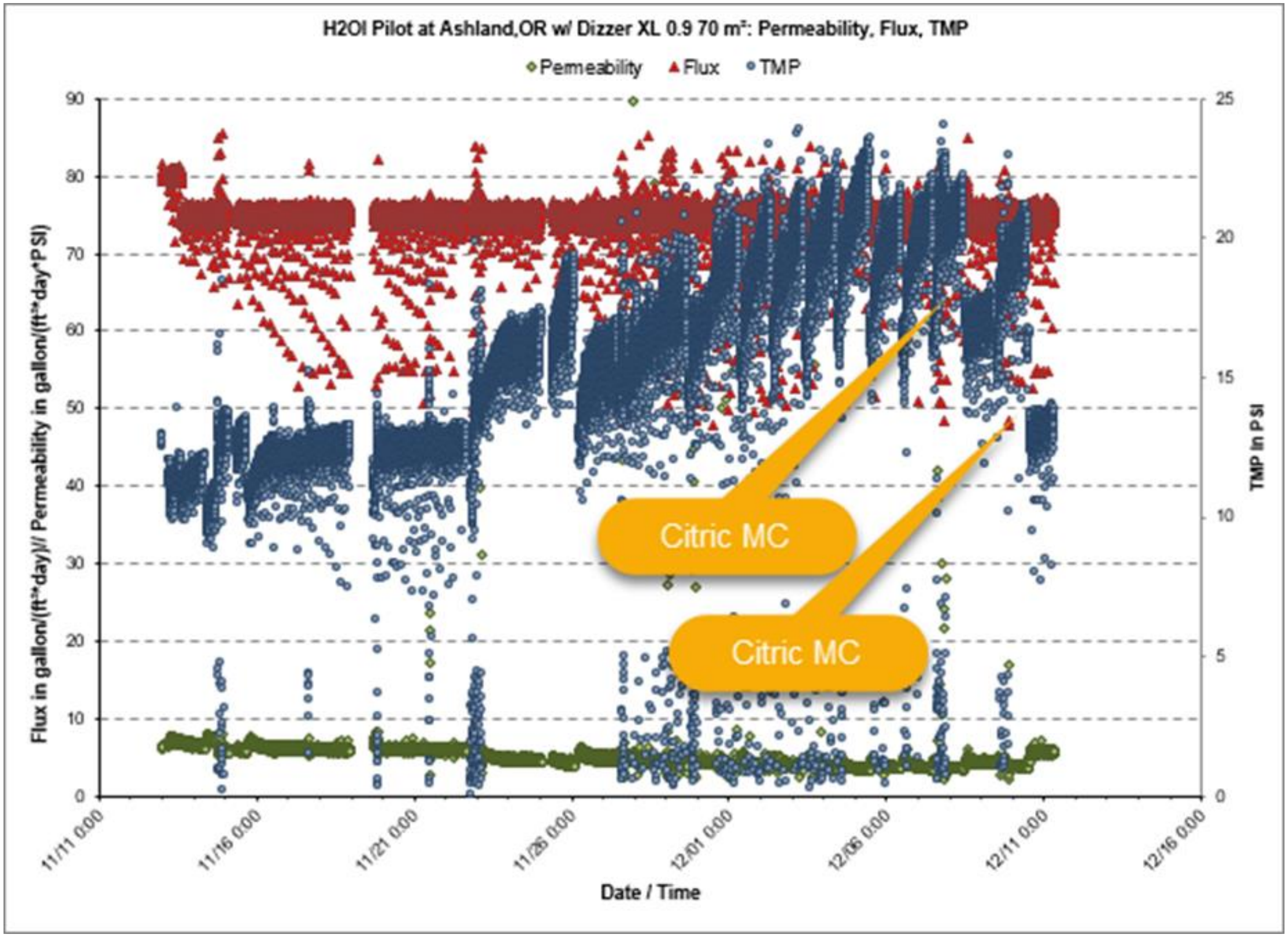
7.5. Design Run #3 Annotated Data-Plot use of Citric Acid during Maintenance Clean from 11/14 – 12/12/17 (Figure #9)



We create chemistry

8. Design Run #3 Statistics from 11/14 – 12/12/17 (Table #2)

	Min	Median	Average	Max	Std Dev
Filtrate Flow - data (gpm)	37.00	39.26	39.25	44.80	0.38
Temperature (°F)	37.66	43.04	42.31	47.29	2.24
Feed Pressure (psi)	2.82	23.10	23.12	31.04	3.20
Filtrate Pressure (psi)	2.95	7.33	7.36	9.01	0.25
TMP (psi)	2.14	15.78	15.76	23.76	3.12
TMP Post BW (psi)	0.00	15.66	14.78	23.19	4.78
TMP Pre BW (psi)	0.60	17.26	16.91	24.04	3.50
Temperature (°C)	3.15	6.13	5.73	8.49	1.25
TCF @20°C	1.38	1.48	1.50	1.62	0.06
TMP @20°C (psi)	2.13	10.68	10.49	15.59	1.92
Normalized Flux @20°C (GFD)	100.10	111.13	112.49	134.63	4.50
Permeability @20°C (GFD/psi)	4.86	7.03	7.40	18.89	1.38
Feed Turbidity (NTU)	0.52	0.94	1.14	100.05	3.04
Filtrate Turbidity (NTU)	0.010	0.011	0.011	0.071	0.001

heart of pure water

9. Discussion of Results (Design Run #3)

Figure #5 provides an illustration of the UF filter permance for the duration of Design Run #3. It is clear that an upset occurred on 11/22/17 which the cleaning steps were not effective enough to recover the previous TMP. The TMP suddenly jumped on 11/22 which ise indicative of an upset condition. It was discovered that the coagulant drum ran dry over the Thanksgiving weekend. The drum was refilled on 11/27. There was a brief reduction in TMP, however, the TMP continued to climb.

During the weekly pilot teleconference, the engineer indicated that coagulation injection pump was inadventally placed in manual mode upon restarting the chemical injection, it was indicated by the engineer that the dose of coagulant was 3x (or more) higher than the target 8 ppmw. In a short period of time, the inge UF experienced organic fouling due to insufficient coagulant followed by inorganic and solids fouling due to excessive coagulant, while operating at a flux of 75 GFD.

Figure #9 clearly shows the beneficial effect of adding citric acid to the standard acid MCs. The citric acid significantly cleaned the excess coagulant, thereby reducing the TMP and improving the membrane permeabilty. After the 2 citric acid MC, the TMP returned to a very sustainable state with a TMP range 12-14 psi which was comparable to the beginning of Design Run #3.

To recap, the Design Run #3 was marked by two unfortunate events which caused the membrane to foul:

- First was the lack of coagulant for 3-4 days during the Thanksgiving weekend
- Second was the excessive dose of coagulant being added to the feed for 2-3 days. When the correct dosage was returned, the membrane did not recover with standard MC and continued to operate at high TMP until citric acid was used.

However, if we ignore the two events above and compare the early data and the last data only, we can note that the initial maximum TMP was 12 psi on 11/14/2017 and the final maximum TMP was 14.67 psi on 12/12/17 which represents a TMP increase of 0.1 psi/day over the entire Design Run #3. This seemed to confirm that there is no irreversible fouling after the upsets.

The higher operating flux during Design Run #3 yields a higher TMP on the UF module compared to Design Run #2. This results in a smaller TMP operating range before the maximum operating TMP for the proposed UF system of 20 psi is reached.

The data from (Design Run #3) should be used for the WTP design basis for operation from June through September. June 1st to May 31st would be approximately 122 days.

For the water treatment plant to operate under inlet head pressure alone the pressure drop from the UF water system has to be under 20 psi. At a flux rate of 75 GFD, a CIP frequency of once every 2 months would maintain a maximum TMP range from 12 psi to 18.5 psi between the start of June and the end of September based on the TMP increase of 0.1 psi/day experienced during Design Run #3.

The recovery for Design Run #3 was 96.4%.

10. Clean in Place (CIP)

A Clean in Place (CIP) was conducted at the end of each design run. The first CIP wash uses a high pH cleaning solution and the second CIP wash uses a low pH cleaning solution. A rinse step as well as a filtrate and BW sequence occur between the high and low pH washes.

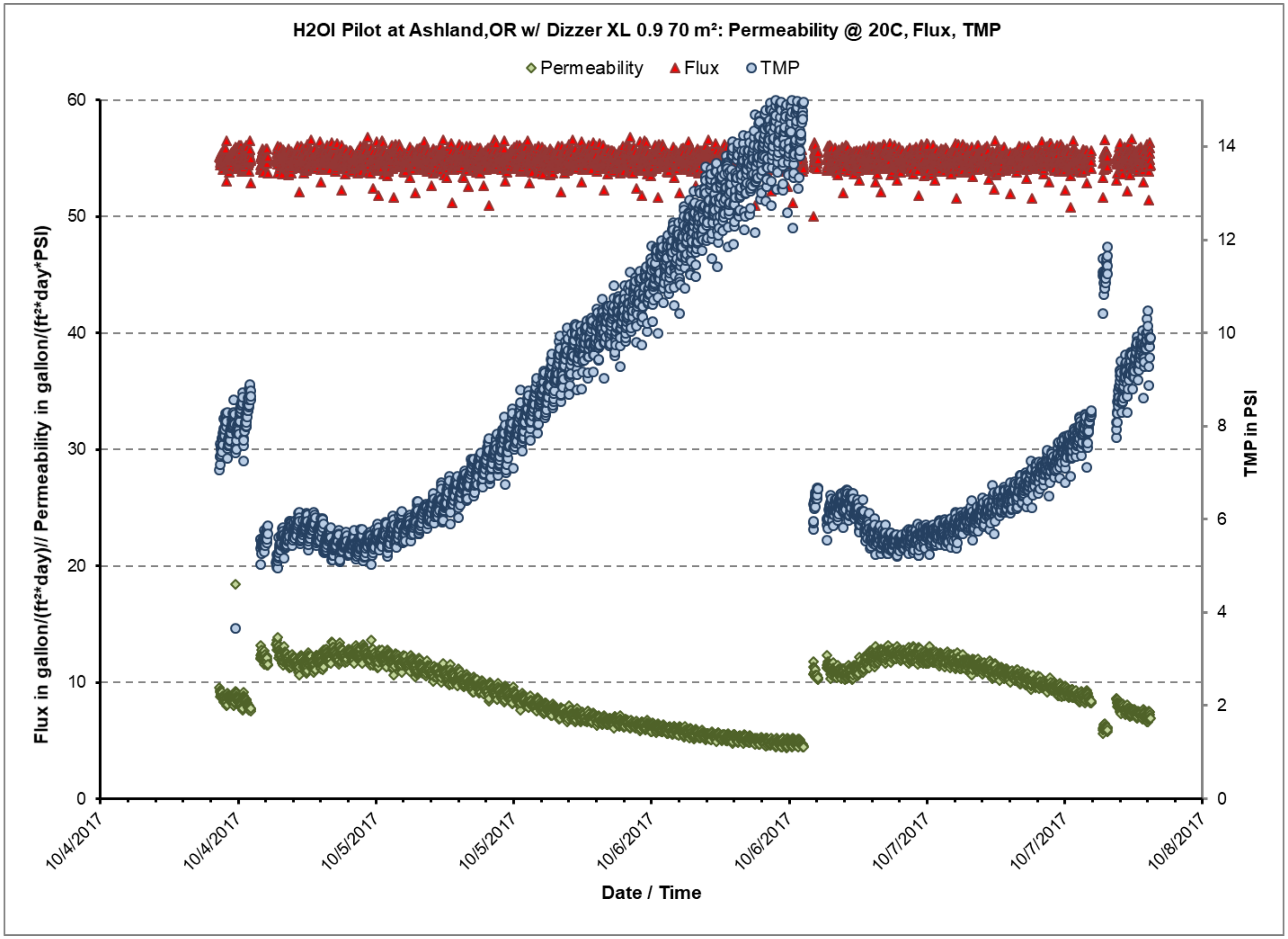
The post CIP permeability @20°C is used to measure the effectiveness of the CIP. The data are summarized below.

Permeability@20°C	**Post Design Run #1**	**Post Design Run #2**	**Post Design Run #3**
Reference	Figure #10	Figure #11	Figure #12
Start of data	10/04/17 @ 2:00 PM	11/06/17 @ 6:15 PM	12/12/17 at 6:00 PM
End of data	10/05/17 @ 5:00 PM	11/07/17 @ 2:00 PM	12/13/17 at 9:30 AM
Max	13.86	11.80	13.84
Min	10.10	8.77	10.36
Average	11.91	10.95	12.03
Std. Dev.	0.57	0.49	0.41

The post CIP permeability values after Design Run #1 and Design Run #3 were both over 13.5 GFD/psi which prove that there was no irreversible fouling. The post CIP permeability value after Design Run #2 was a little lower than those of Design Run #1 and #3 but it should not raise any concern since it was not a trend.

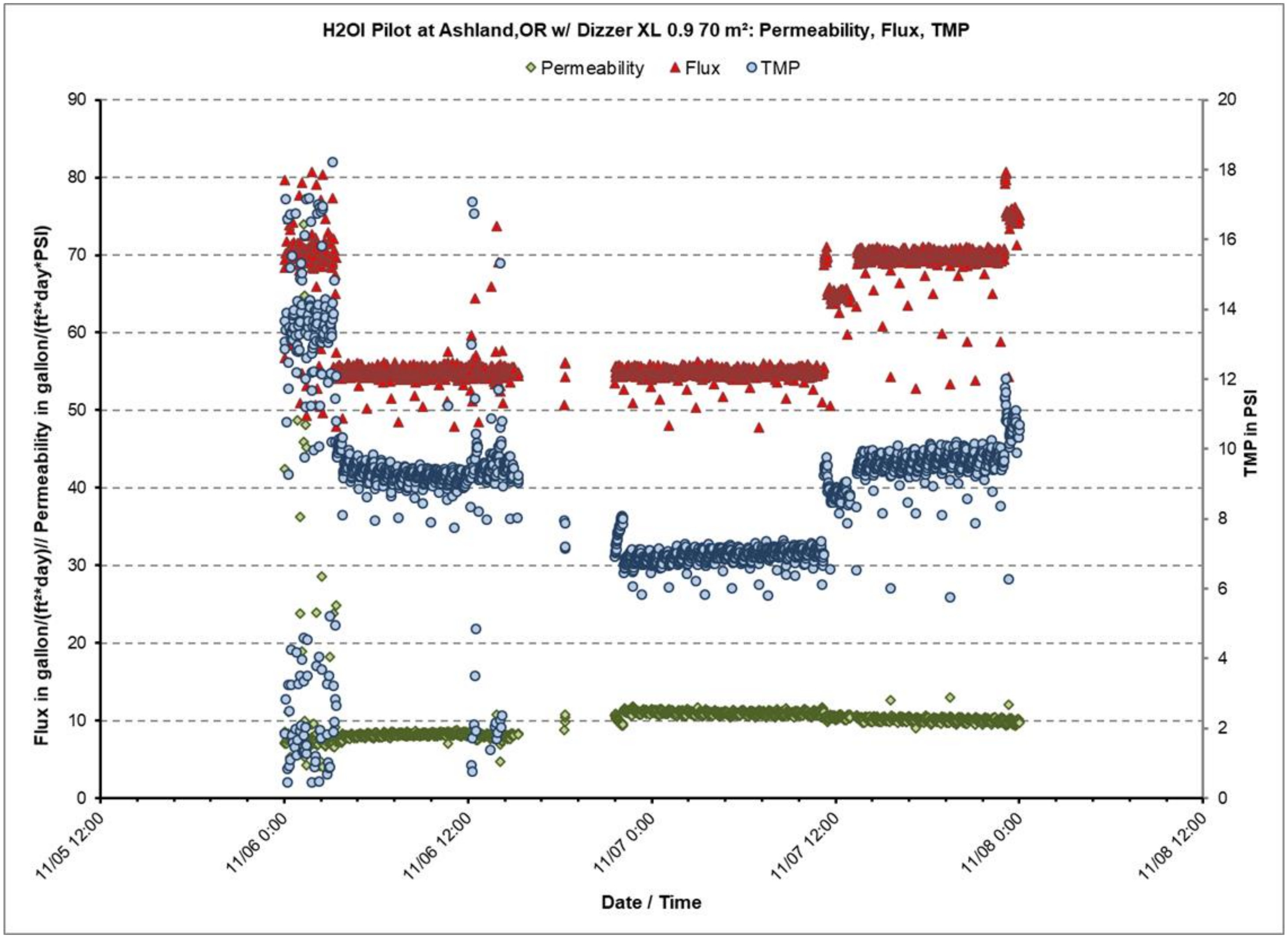
We create chemistry

CIP after Design Run #1 (Figure #10)



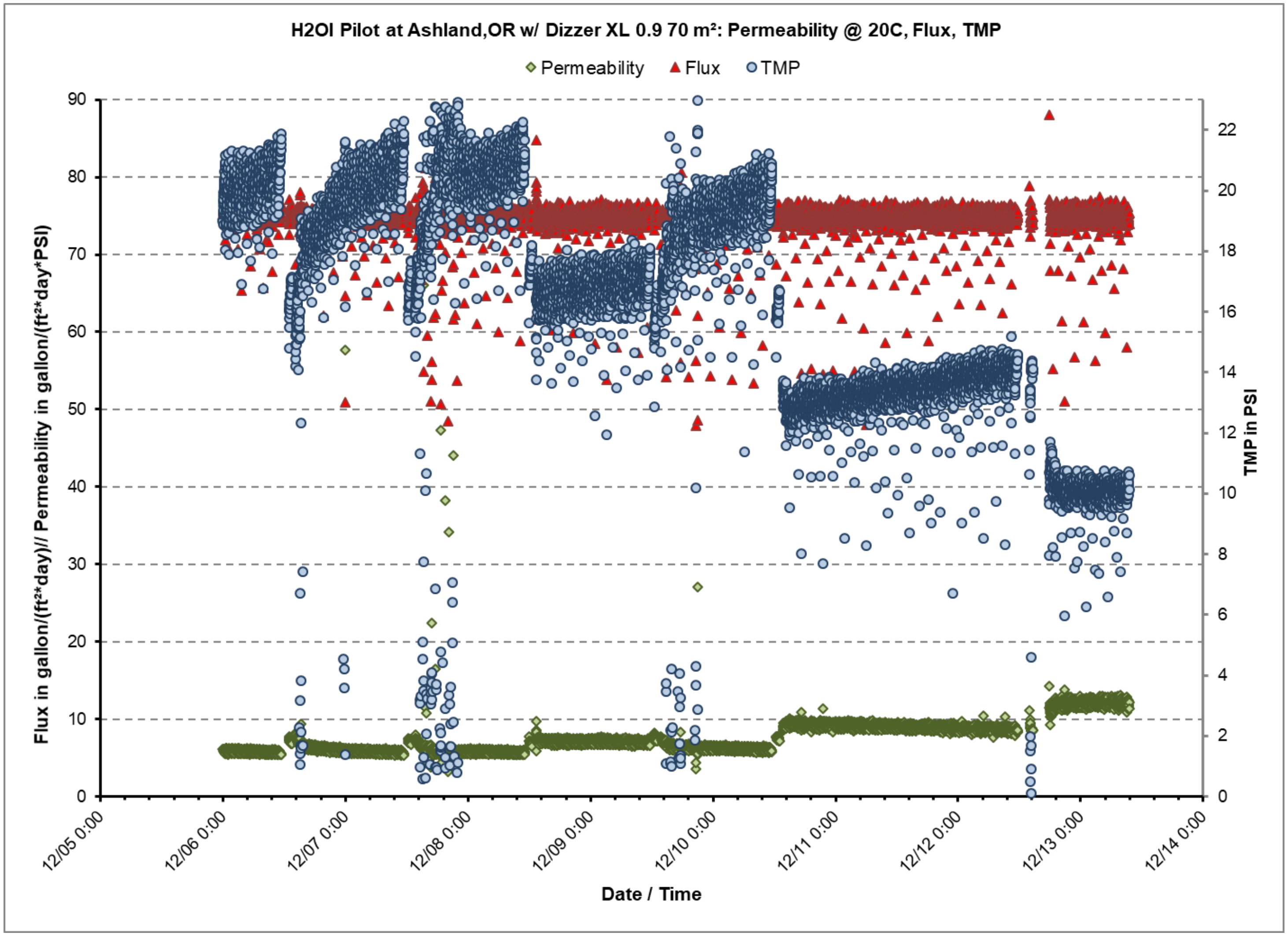
heart of pure water

CIP after Design Run #2 (Figure #11)



We create chemistry

CIP after Design Run #3 (Figure #12)

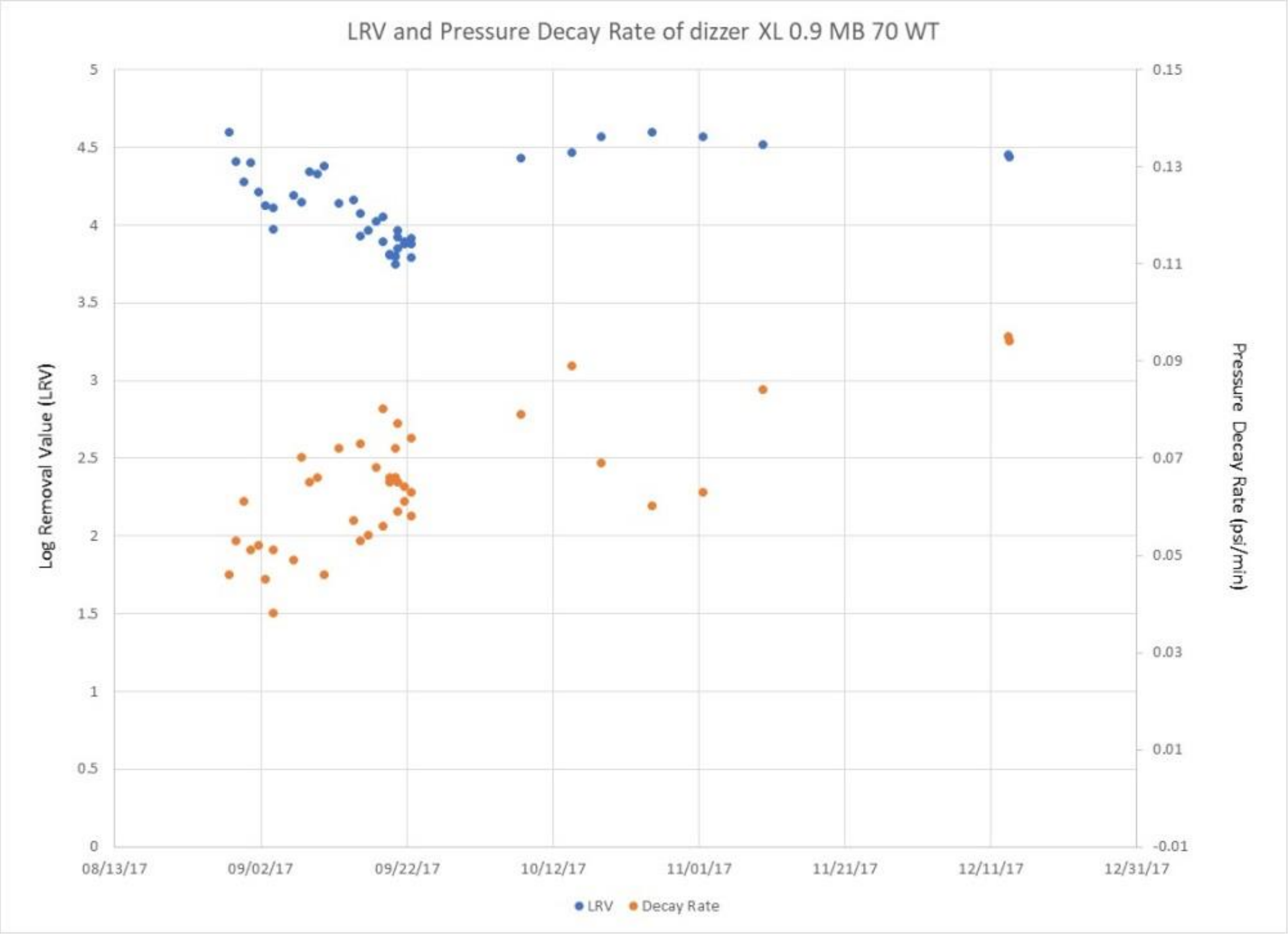


heart of pure water

11. Direct Integrity Tests

The pressure decay rate improved in October after loose connectors on the feed piping were retightened. If a fiber breach exists, then air will pass from the feed side to the filtrate. No air bubbles were observed in any of the witnessed direct integrity tests.

11.1. Direct Integrity Test Results (Figure #13)



12. Conclusions and Recommendations

Based on the pilot data from Design Run #2 and Design Run #3, the following conclusions can be made for the inge® Multibore® UF:

1. Ability to operate at 55 GFD with an average TMP of 5.5 psi (20^{o}C) with 2 MC/week
2. Ability to operate at 75 GFD with an average TMP of 10.5 psi (20^{o}C) with 3 MC/week
3. Filtrate quality always < 0.03 NTU
4. Recovery > 95%
5. Addition of ACH reduced organic fouling resulting in low TMP
6. Overdose of ACH caused metal fouling resulting in rapid TMP rise. But the addition of citric acid into the MC process significantly improved cleanability of the membrane and restored its permeability
7. No irreversible fouling was observed
8. The membrane passed direct integrity tests until the end of the pilot study