Public Health Division
Center for Health Protection, Drinking Water Services
Tina Kotek, Governor
OREGON HEALTH AUTHORITY

September 11, 2024

Kathleen Anderson
Buell-Red Prairie Water District
PO Box 367
Sheridan, OR 97378
admin@brpwater.com

Letter sent only via e-mail.

Re: Buell-Red Prairie Water District (PWS ID# 01174)
Membrane Module Replacement with 12 Toray HFUG-2020AN Modules
Final Approval – PR# 27-2024

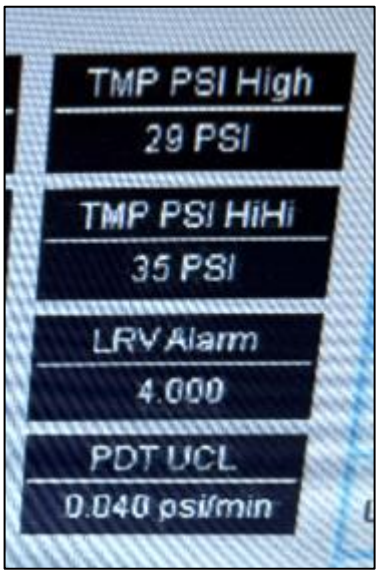
Dear Ms. Anderson:

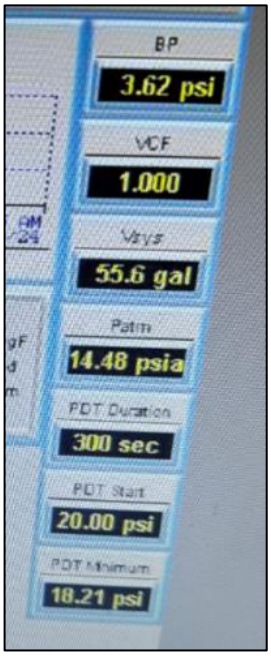
The survey letter dated January 8, 2023 issued by my colleague, Michelle Byrd, identified deficiencies related to the membrane filtration system, which included not completing plan review and related programming needed to verify the membrane integrity (e.g., $LRV_{ambient}$ and direct integrity testing (DIT) parameters). On February 15, 2024, we received a plan review fee payment of $825 and programming pressure decay testing calculations and variables were received on April 12, 2024. Programming was largely completed on April 16, 2024, by Chaz Hooley with TAG with the assistance of Dan Dye and Cody Maxfield with WesTech.

The project involved replacing the 12 existing Toray HFS-2020 membrane modules (installed in 2012-2013 in two WesTech AltaPac Customized for Buell-Red Prairie Water District (CBRPWD) filtration skids (originally installed in 2009 (PR#84-2009) having a capacity of up to 6 modules per skid) with a total of **12 new Toray HFUG-2020AN ultrafiltration PVDF hollow fiber membrane modules (6 modules per skid)**.

The new modules were installed in 2019 with $LRV_{ambient}$ programming implemented this year with the final logic and SCADA screens received 4-18-24.

The project is granted <u>Final Approval</u> with the pathogen removal credits in Table 1 and operating limits in Table 2.





Please note:

- *The TMP PSI HiHi alarm is set to 35 psi and should be 29 psi or less and the backpressure (BP) is set to 3.62 psi rather than 3.64 psi WesTech specified.*
- *The backpressure was revised to 3.64 psi, however the revision was not known until after the programming work was already completed by TAG.*
- *Although these changes have a negligible effect on $LRV_{ambient}$ and the direct integrity test pressure, these values should be updated with any future programming changes.*
- *WesTech should be consulted to see if the TMP PSI HiHi alarm should be revised sooner and to what value (less than 29 psi).*

Each of the two membrane filter units is granted log removal credits (LRCs) for pathogen removal as shown in Table 1. The LRCs are based on a verification of the Challenge Study Report from the National Sanitation Foundation (NSF) dated August 15, 2019 (NSF job #J-00320592) for the installed Toray HFUG-2020AN membrane modules.

Table 1 – Filter Log Removal Credit (LRC)

Pathogen	Removal Credit (log_{10})
Giardia lamblia	4.0
Cryptosporidium sp.	4.0
Viruses	0.0

The LRCs are only valid provided operations are within the limits shown in Table 2. Ensure SCADA/PLC programming continues to account for the operating limits in Table 2 (e.g., set system alarms to ensure operating limits are met).

Table 2 – Operating Limits

Operating Parameter	Limit
Direct integrity test (DIT) frequency	**Conduct at least 1 DIT each day of operation**
DIT duration/hold time	5 minutes
DIT starting test pressure	**20 psi**
Minimum allowed DIT pressure	**18.23** psi throughout the DIT duration @ BP=3.64 psi. (starting test pressure set point is 20 psi with a minimum set point of 18.2 psi)
Maximum allowable pressure decay rate (PDR_{max}) upper control limit (UCL)	**UCL = PDR_{max} = 0.04 $^{psi}/_{min}$** (a PDT alert is set at 0.039 psi/min and an alarm is set at 0.04 psi/min)
Minimum DIT pressure transducer accuracy for the established UCL[1]	**± 0.065% of span (0-30 psi), 0.0039 psi/min for the Rosemount 3051 pressure transducer installed (0.065% x 30 psi/5 min = 0.0039 psi/min).**
Membrane Minimum Performance ($LRV_{ambient}$)	**$LRV_{ambient}$ = 4.0-log (must be ≥ 4.0-log LRC)**
DIT Sensitivity (LRV_{DIT})	**4.97-log_{10} at PDR = 0.0039 $^{psi}/_{minute}$ and flow of 65 gpm**. (4.0-log at PDR = 0.04 psi/min and flow of 65 gpm).
$LRV_{ambient}$	**$LRV_{ambient}$ should be greater than or equal to 4.0-log_{10}**
Maximum transmembrane pressure (TMP)	**29 psi** at 20°C (the high-high TMP alarm is set to 35 psi)
Maximum allowed filtrate flux [gfd]	**120 $^{gal/SqFt}/_{day}$** @ 20°C. This max flux yields a peak plant production of **484.5 gpm using 6 out of 6 possible modules per skid** (**80.75 gpm/module**). 55 gpm is programmed into the PLC as the maximum design flow per skid (43 $^{gal/SqFt}/_{day}$)
Individual filter effluent (IFE)	IFE ≤ 0.15 NTU for ≥ 15 consecutive minutes
Combined filter effluent (CFE) turbidity	CFE ≤ 1 NTU in 95% of readings and always less than 5 NTU
Automatic Shutdown Conditions (shut filter train down and conduct a DIT to demonstrate membrane integrity is intact)	○ PDR > UCL ○ $LRV_{ambient}$ < LRC ○ IFE > 0.15 NTU for > 15 min ○ CFE > 5.49 NTU (may prompt boil water notice)

[1] **Pressure transducer accuracy** is based on the manufacturer's stated accuracy (best fit straight line), expressed as % of span. The accuracy calculated in terms of [psi/min] must be less than or equal to the UCL in [psi/min]. Accuracy in terms of [psi/min] is calculated as follows:

Accuracy in psi/min = (% Accuracy x Max of span in psi) / DIT duration in minutes

$LRV_{ambient}$ is the best metric for demonstrating compliance with the log removal credit (LRC) granted. **To remain in compliance, $LRV_{ambient}$ must be equal to or greater than the 4.0-log LRC for *Cryptosporidium* shown in Table 1**. $LRV_{ambient}$ is calculated using the formulae, constants, and variables shown in Table B-1 of Appendix B. The remainder of this letter includes the following:

1) Project Description
2) Appendix A - Explanation of operating limits and terms in Table 2.
3) Appendix B – Formulae, constants, and variables used in calculating the log removal value ($LRV_{ambient}$) of each membrane filter unit/train using current (ambient) operating conditions.
4) Appendix C – Product specifications for the selected membrane modules.
5) Appendix D – SCADA Screens and PLC programming from 4-24-24

Thank you for your cooperation during this process and if you have any questions on the information above, or would like this information in an alternate format, please contact me at 971-200-0288 or via e-mail at evan.e.hofeld@oha.oregon.gov.

Sincerely,

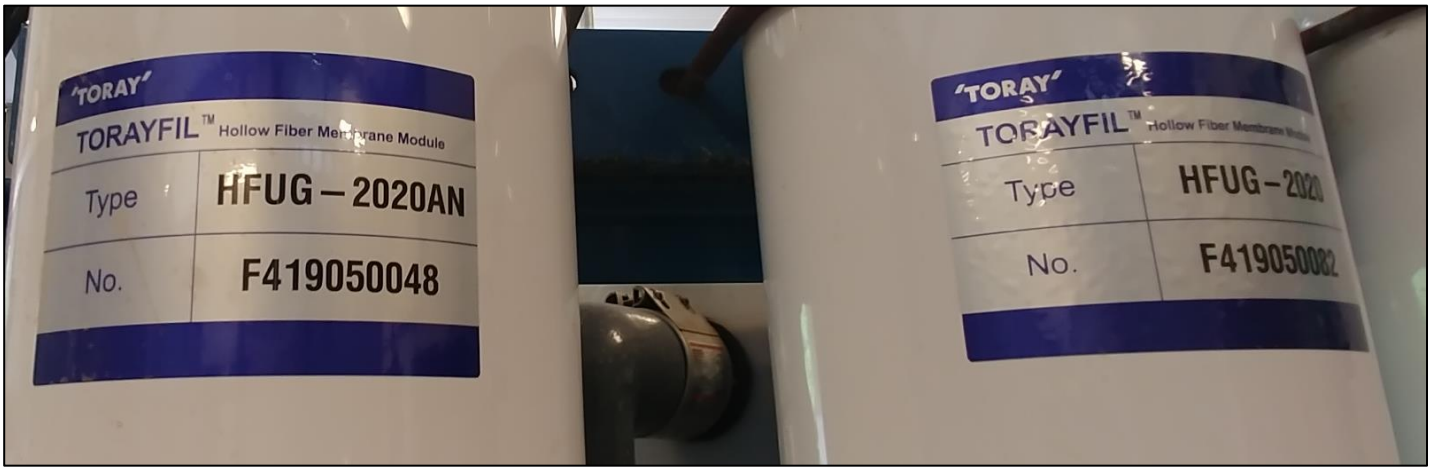
Evan Hofeld, PE
Regional Engineer
Oregon Health Authority - Drinking Water Services

cc. Heath Cokeley, OAWU (hcokeley@oawu.net)
Chaz Hooley, TAG (chooley@tag-inc.us)
Cody Maxfield, WesTech (CMAXFIELD@westech-inc.com)
Dan Dye, WesTech (DDYE@westech-inc.com)

Project Description:

During the July 20, 2021, water system survey it was discovered that the 12 existing Toray HFS-2020 membrane modules installed in 2012-13 (6 modules per skid in two WesTech Customized for Buell-Red Prairie Water District (CBRPWD) ultrafiltration skids) had been replaced in 2019 with a total of 12 Toray HFUG-2020AN ultrafiltration PVDF hollow fiber membrane modules (6 modules per skid). This was identified as a significant deficiency in the water system survey report. An extension was granted until April 30, 2024, granting additional time needed to resolve this deficiency. A plan review fee of $825 was requested on 12/27/2023 and paid on 2/15/24. The final LRV calculations were received from Cody Maxfield with WesTech (CMAXFIELD@westech-inc.com).

Although the modules have two different labels affixed with one indicating module type "HFUG-2020AN" and the other indicating "HFUG-2020", Sue Guibert with Toray confirmed the HFUG-2020 label is a misprint – all the modules installed in 2019 are HFUG-2020AN.



Appendix A
Explanation of operating limits and terms in Table 2.

The ability of membranes to filter out pathogens (referred to as **membrane integrity**) is to be tested in two ways:

- Continuously using a turbidimeter that monitors the effluent turbidity from each membrane unit, often called **individual filter effluent (IFE)** turbidity monitoring, and
- Once a day using a more direct pressure decay or "air hold" test, often called a **"Direct Integrity Test" (DIT)** because the air hold test is a direct test for leaks or broken membrane fibers.

Direct Integrity Testing (DIT):
Like checking for leaks in a car tire, the membranes are pressurized with air and held for a set amount of time. Air hold times are generally 2 – 10 minutes. A pressure sensor then detects a drop in the held pressure. This pressure drop is called a pressure decay, measured in psi. How fast the pressure drops (or decays) is called the **pressure decay rate (PDR)**, measured in psi/minute. The pressure decay rate is the drop in pressure (psi) divided by the air hold time (minutes) expressed in psi/minute. In some cases, the SCADA will display only the pressure decay in psi and it is up to the operator to know the hold time and determine the decay rate in psi/minute.

Demonstrating compliance:
Should individual filter effluent turbidity exceed 0.15 NTU for more than 15 consecutive minutes, the membrane unit needs to be taken out of service and undergo a direct integrity test. Turbidity is an indirect indicator of membrane integrity and requires a direct integrity test (DIT) to directly determine membrane integrity.

In order for a DIT to be able to demonstrate that the membranes are intact (do not have holes or broken fibers), the membrane needs to be pressurized to a certain minimum pressure (the **minimum direct integrity test pressure**) and the pressure decay rate needs to be under a specified upper limit or **"Upper Control Limit" (UCL)**.

The results of the DIT can be used to calculate a pathogen removal efficiency under ambient operating conditions achieved by the membranes. This log removal value is termed **"$LRV_{ambient}$"** and can be used to demonstrate compliance by directly comparing this performance metric to the log removal credit (**LRC**) *Cryptosporidium* awarded in Table 1. More detail on the terms introduced above and the operating limits (e.g., upper control limit, etc.) in Table 2 are further described on the following page.

- DIT Turbidity Trigger (IFE > 0.15 NTU for > 15 min): A direct integrity test (DIT) must be performed on each filter unit if the individual filter effluent (IFE) turbidity is greater than 0.15 NTU for more than 15 minutes. This must be programmed into the SCADA system. Should the IFE turbidity exceed 0.15 NTU for more than 15 minutes, the membrane unit must be taken out of service and undergo a DIT. The membrane unit must not be placed back into service unless it passes the DIT (see Upper Control Limit below). Membrane fiber repair/pinning is often needed to remedy this situation.

- DIT Daily Trigger: A DIT is also required each day of operation. If the pressure decay rate (PDR) drops below the upper control limit (UCL in $^{psi}/_{minute}$), then the DIT is considered to have failed and the unit must be automatically taken off-line & repaired and/or retested to show that it passes a DIT before being placed back into service. In other words, should the PDR of the daily PDT (or "air hold test") exceed the UCL, this should indicate a "failed" DIT and the membrane must be taken out of service and may not be placed into service until it passes a DIT. **A new DIT may be immediately run after a DIT failure, or repairs may be needed first (e.g., fibers pinned, leaks at pipe fittings repaired, etc.) followed by passing a new DIT.**

- DIT test pressure: The minimum DIT pressure (i.e., the test pressure at the end of the DIT) must not drop below the minimum DIT pressure stated in Table 2. **Should the pressure during a DIT drop below the level in Table 2, the DIT is considered invalid or "failed" and must be repeated. Starting test pressures are often established (with consultation with the membrane manufacturer) above the minimum DIT pressure to ensure that the test is valid.**

- Upper Control Limit (UCL) and PDR_{max} in $^{psi}/_{min}$
  Every membrane system has an Upper Control Limit (UCL) measured in $^{psi}/_{min}$. The UCL is the same as the PDRmax value on the monthly reporting form and is the highest **p**ressure **d**ecay **r**ate (PDR) allowed during a direct integrity test (DIT). Exceeding the UCL indicates DIT failure. The failing membrane unit shall not operate until it passes a DIT. Ensure that the SCADA/PLC system is programmed to account for this UCL.

- Membrane Performance ($LRV_{ambient}$): The results of the direct integrity test will be used to determine the log removal value of *Cryptosporidium* that is based on ambient or current operating conditions ($LRV_{ambient}$). The main difference between LRV_{DIT} (see DIT sensitivity on the following page) and $LRV_{ambient}$ is the use of the current operating flow when calculating $LRV_{ambient}$. Lower flows could yield a lower (less conservative) LRV value. Since the pathogen removal credit is in terms of a log removal value,

membrane performance must be determined to demonstrate compliance with the pathogen credit awarded using the same unit of measure [log]. Formulae, constants and variables used to calculate $LRV_{ambient}$ are included in Appendix B of this letter. In summary, $LRV_{ambient}$ is the metric for demonstrating compliance. $LRV_{ambient}$ must be equal to or greater than the log removal credit for *Cryptosporidium* shown in Table 1.

- TMP: The transmembrane pressure or "TMP" is the pressure drop across the membranes and must not exceed that indicated in Table 2. The log removal credit is awarded based on this TMP as it reflects the operating conditions at the time of the challenge study conducted to demonstrate the membrane's ability to remove *Cryptosporidium*.

- Flux: The flux ($^{flow}/_{filter\ feed\ area}$) is the flow per square feet of membrane surface area on the feed or inlet side of the membranes per day [$^{gal/SqFt}/_{day}$ or "gfd"]. The flux must not exceed that indicated in Table 2. The log removal credit is awarded based on this flux as it reflects the operating conditions at the time of the challenge study conducted to demonstrate the membrane's ability to remove *Cryptosporidium*.

- Automatic Shutdown Conditions: **The filters must be taken off-line or otherwise shut down, repaired and/or re-tested if any of the following occurs:**

  1. PDR > UCL. The DIT PDR exceeds the UCL in Table 2.
  2. $LRV_{ambient}$ < LRC. The $LRV_{ambient}$ is less than the log removal credit (LRC) in Table 1
  3. IFE > 0.15 NTU for > 15 min. The individual filter effluent (CFE) turbidity exceeds 0.15 NTU for more than 15 minutes.
  4. Combined Filter Effluent (CFE) turbidity exceeds 5.49 NTU (your regulator should be contacted should CFE turbidity exceed 1 NTU. A boil notice may be required above 5.49 NTU).

- DIT Sensitivity (LRV_{DIT}): The results of the direct integrity test (pressure decay rate or "PDR") and the design flow can be used to determine the DIT sensitivity, expressed as a log removal value of *Cryptosporidium* (LRV_{DIT}). This LRV_{DIT} is calculated as shown in Appendix B and must be equal to or greater than the log removal credit (LRC) shown in Table 1.

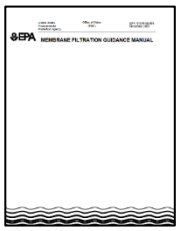
Appendix B

Formulae, constants, & variables used in calculating the log removal value ($LRV_{ambient}$) of each membrane filter unit using current ambient operating conditions.

Table B-1. Formulae and variables used in the $LRV_{ambient}$ programming

Specification	Value
$LRV_{ambient}$ equation	$LRV_{ambient} = \log_{10}\left(\frac{Q_P \bullet ALCR \bullet P_{atm}}{\Delta P_{test} \bullet V_{sys} \bullet VCF}\right)$
P_{atm}, Atmospheric pressure [psia]	Constant = 14.48 psi (same for ALCR)
VCF, Volumetric Concentration Factor [dimensionless]	Constant = 1 (deposition mode)
VCF for backwash units in which filtrate goes to clearwell	N/A - no backwash recovery units
V_{sys}, Total volume of pressurized air in the unit during direct integrity testing and volume per module [gallons and liters]	Constant = 55.6 gallons (210.47 liters = 0.21047 m^3) for 4 Toray HFUG-2020AN modules per skid (11.88 $^{gallons}/_{module}$ = 44.97 $^{liters}/_{module}$)
Q_p, filtrate flow of filter unit	Variable - for $LRV_{ambient}$ calculations (65 gpm design flow)
ΔP_{test}, DIT pressure decay rate [psi/min]	Variable - based on the pressure decay rate for most recent direct integrity test
Constants needed if ALCR is calculated using the Hagen-Poiseuille equation for laminar flow (Hagen-Poiseuille, MFGM[1] Eq. C.4) ☒ *Not applicable as Darcy equation is used for ALCR*	$ALCR = \frac{527 \bullet \Delta P_{eff} \bullet (175 - 2.71 \bullet T + 0.0137 \bullet T^2)}{TMP \bullet (460 + T)}$ $\Delta P_{eff} = [(P_{test} - BP)] \bullet \left[\frac{(P_{test} + P_{atm}) + (BP + P_{atm})}{2 \bullet (BP + P_{atm})}\right] \bullet \left[\frac{(BP + P_{atm})}{P_{atm}}\right]$
P_{atm}, Atmospheric pressure [psia]	Constant = 14.48 psi (used w/ $LRV_{ambient}$)
BP, Backpressure during the DIT [psi]	Constant[3] = 3.64 psi = 100.875 inches of water.
P_{Test} used for ΔP_{eff} equation [psi]	Constant[4] = 18.23 psi @ 3.64 psi BP
T, Feed water temperature [°F]	Variable - used for ALCR (e.g., 68 °F)
TMP, transmembrane pressure [psi]	Variable - used for ALCR (e.g., 29 psi)
Constants needed if ALCR is calculated using the Darcy equation for turbulent flow (Darcy, MFGM[1] Eq. C.4) ☐ *Not applicable as Hagen-Poiseuille equation is used for ALCR*	$ALCR = 170 \bullet Y \bullet \sqrt{\frac{(P_{test} - BP) \bullet (P_{test} + P_{atm})}{(460 + T) \bullet TMP}}$
Y, Net Expansion Factor [dimensionless][2]	Calculated value[5]

[1] MFGM = Membrane Filtration Guidance Manual (USEPA, Nov. 2005)
[2] Crane Co. 1988. *Flow of fluids through valves, fittings, and pipe*. Technical Paper No. 410. Stamford, CT.
[3] PLC programming is using 3.62 psi, which yields a minimum DIT test pressure of 18.21 psi.
[4] PLC programming is using the UCL of 20 psi for P_{test} in the ΔP_{eff} equation, which will yield a lower and more conservative ALCR and lower $LRV_{ambient}$.
[5] PLC programming uses the following formula to calculate the net expansion factor:
Y = 1 - 0.543*((Pf - BP)/(Pf+Patm)), where Pf is the direct integrity test ending test pressure (PLC Tag PDTfinalREAL).



The Upper Control Limit (UCL) is the maxium pressure decay rate (PDRmax) resulting from a pressure decay test that is allowed and that if exceeded, requires that the filter unit be shut down and repaired and/or re-tested. The UCL for Buell-Red Prairie's two WesTech AltaPac Customized for Buell-Red Prairie Water District (CBRPWD) UF filtration skids containing 6 Toray HFUG-2020AN ultrafiltration modules each was calculated using the following equations published in the Membrane Filtration Guidance Manual (USEPA, Nov. 2005), herein referred to as the "MFGM".

Table 4.1 Approaches for Calculating the ALCR

Module Type	Defect Flow Regime	Model	ALCR Equation	Appendix C Equation
Hollow-fiber[1]	Turbulent[2]	Darcy pipe flow	$170 \bullet Y \bullet \sqrt{\frac{(P_{test}-BP)\bullet(P_{test}+P_{atm})}{(460+T)\bullet TMP}}$	C.4
	Laminar	Hagen-Poiseuille[3]	$\frac{527 \bullet \Delta P_{qf} \bullet (175-2.71 \bullet T+0.0137 \bullet T^2)}{TMP \bullet (460+T)}$	C.15
Flat sheet[4]	Turbulent	Orifice	$170 \bullet Y \bullet \sqrt{\frac{(P_{test}-BP)\bullet(P_{test}+P_{atm})}{(460+T)\bullet TMP}}$	C.9
	Laminar	Hagen-Poiseuille[3]	$\frac{527 \bullet \Delta P_{qf} \bullet (175-2.71 \bullet T+0.0137 \bullet T^2)}{TMP \bullet (460+T)}$	C.15

1 Or hollow-fine-fiber
2 Typically characteristic of larger diameter fibers and higher differential pressures
3 The binomial in the Hagen-Poiseuille equation (C.15) approximates the ratio of water viscosity to air viscosity and is valid for temperatures ranging from approximately 32 to 86 °F. Additional details are provided in Appendix C.
4 Includes spiral-wound and cartridge configurations

The UCL is related to the minimum direct integrity test (DIT) pressure, which typically occurs at the end of the DIT air hold time. In order to achieve a resolution of 3 µm required for pressure-based direct integrity tests, the net pressure applied during the test must be great enough to overcome the capillary forces in a 3 µm hole, thus ensuring that any breach large enough to pass *Cryptosporidium* oocysts would also pass air during the test. A DIT that does not maintain at least this minimum test pressure throughout the duration of the entire air hold time is considered a failed test and may indicate either breaches or broken membrane fibers or a leak in the air hold system and should prompt immediate repair and re-testing. The minimum applied test pressure necessary to achieve the required test resolution of 3 µm was calculated using MFGM Equation 4.1 as follows:

Minimum Required DIT pressure [psi] to meet the required 3 µm resolution requirement

P_{Test} = 18.23 psi is the minumum required DIT test pressure (e.g., minimum DIT ending test pressure) in order to meet the 3 µm test resolution calculated using MFGM equation 4.1 where,

$$P_{Test} = (0.193 \bullet \kappa \bullet \sigma \bullet \cos \theta) + BP_{max}$$

0.193 = constant that includes the defect diameter (i.e., 3 µm resolution requirement) and unit conversion factors

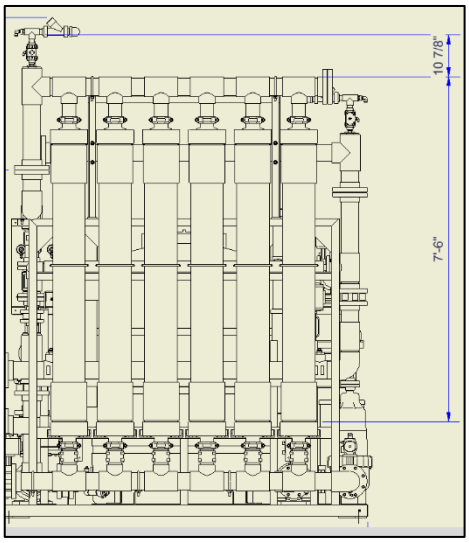
κ = 1, dimensionless pore shape correction factor

σ = 75.6 dyne/cm, surface tension at the air-liquid interface at 5°C

θ = 0 degrees (0 radians), liquid-membrane contact angle

BP_{max} = 3.64 psi (100.875 inches of water), maximum backpressure during the direct integrity test

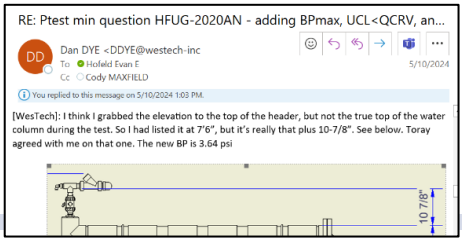
D_{base} = 0 psi/min, baseline decay through diffulsive losses assuming a fully intact membranes (i.e., no broken fibers, or holes in the membranes).



1. Calculate the minimum Direct Integrity Test (DIT) pressure commensurate with the required resolution of 3 µm for the removal of Cryptosporidium

$P_{test\ min} = (0.193 \times K \times \sigma \times \cos \theta) + BP_{max}$
(Equation 4.1 EPA Manual)

K	1 -	Most conservative value
σ	75.6 dynes/cm	Surface tension of water at 5 deg C
θ	0 degrees	Most conservative value
BP_{max}	3.64 psi	Converted from inches of water
Constant	0.193	Constant that includes the defect diameter (i.e. 3 µm resolution requirement) and unit conversion factors
$P_{test\ min}$ =	18.23 psi	P_{test} is the minimum starting pressure for a Pressure Decay Test (PDT)
	125.7 kPa	



Upper Control Limit (UCL) in psi/minute

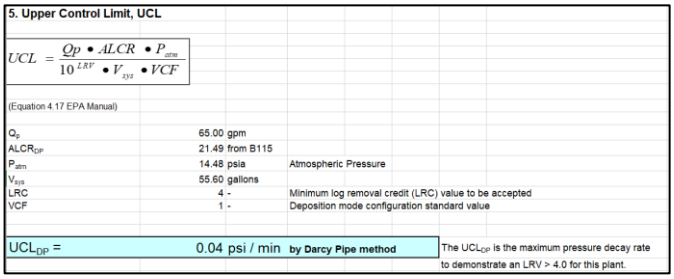
UCL = 0.04 psi/min

- A UCL of 0.0364 psi/min using an ALCR = 21.488
- A UCL of 0.0415 psi/min is obtained using ALCR = 24.54
- A UCL of 0.0395 psi/min is obtained using ALCR = 23.361

UCL is calculated using MFGM equation 4.17 where,

$$UCL = \frac{Q_p \bullet ALCR \bullet P_{atm}}{10^{LRC} \bullet V_{sys} \bullet VCF}$$

Q_p = 65 gpm
P_{atm} = 14.48 psi
LRC = 4.0 log
V_{sys} = 55.6 gallons (210.45-L = 0.210 m^3)
VCF = 1
ALCR = See calculations below



5. Upper Control Limit, UCL

$$UCL = \frac{Qp \bullet ALCR \bullet P_{atm}}{10^{LRV} \bullet V_{sys} \bullet VCF}$$

(Equation 4.17 EPA Manual)

Q_p	65.00 gpm	
$ALCR_{DP}$	21.49 from B115	
P_{atm}	14.48 psia	Atmospheric Pressure
V_{sys}	55.60 gallons	
LRC	4 -	Minimum log removal credit (LRC) value to be accepted
VCF	1 -	Deposition mode configuration standard value
UCL_{DP} =	0.04 psi / min by Darcy Pipe method	The UCL_{DP} is the maximum pressure decay rate to demonstrate an LRV > 4.0 for this plant.

ALCR = 21.488

- An ALCR of 21.466 was determined using TMP = 29 psi, Y = 0.74 & P_{test} = 18.21 psi
- An ALCR of 23.361 was determined using TMP = 29 psi, Y=0.74 & P_{test} = 20 psi

ALCR is calculated using MFGM equation C.4 for turbulent flow through a breach in hollow fiber membranes where,

$$ALCR_{DP} = 170 \bullet Y \bullet \sqrt{\frac{(P_{test} - BP) \bullet (P_{test} + P_{atm})}{(460 + T) \bullet TMP}}$$

P_{test} = 18.23 psi (WesTech uses 20 psi)
T = 104°F (maximum water temperature used by WesTech)
TMP = 29.0 psi (maximum allowed TMP – also used by WesTech)
BP = 3.64 psi (BP_{max})
P_{atm} = 14.48 psi
$(P_{test} – BP) / (P_{test} + P_{atm})$ = 14.59 / 32.71 = 0.446 (0.474 @ 20 psi & 0.4457 @ 18.21 psi)
Y = 0.758 using a test pressure of 18.23 psi based on the BRPWD formula below:

$$Y = 1-(0.543) * [(PDTP_{final}-BP) / (PDTP_{final}+P_{atm})]$$

Where $PDTP_{final}$ is the ending DIT test pressure (SCADA Tag PDTfinalREAL).
Using the BRPWD formula for Y:

Y = 0.7578 using a $PDTP_{final}$ of 18.23 psi

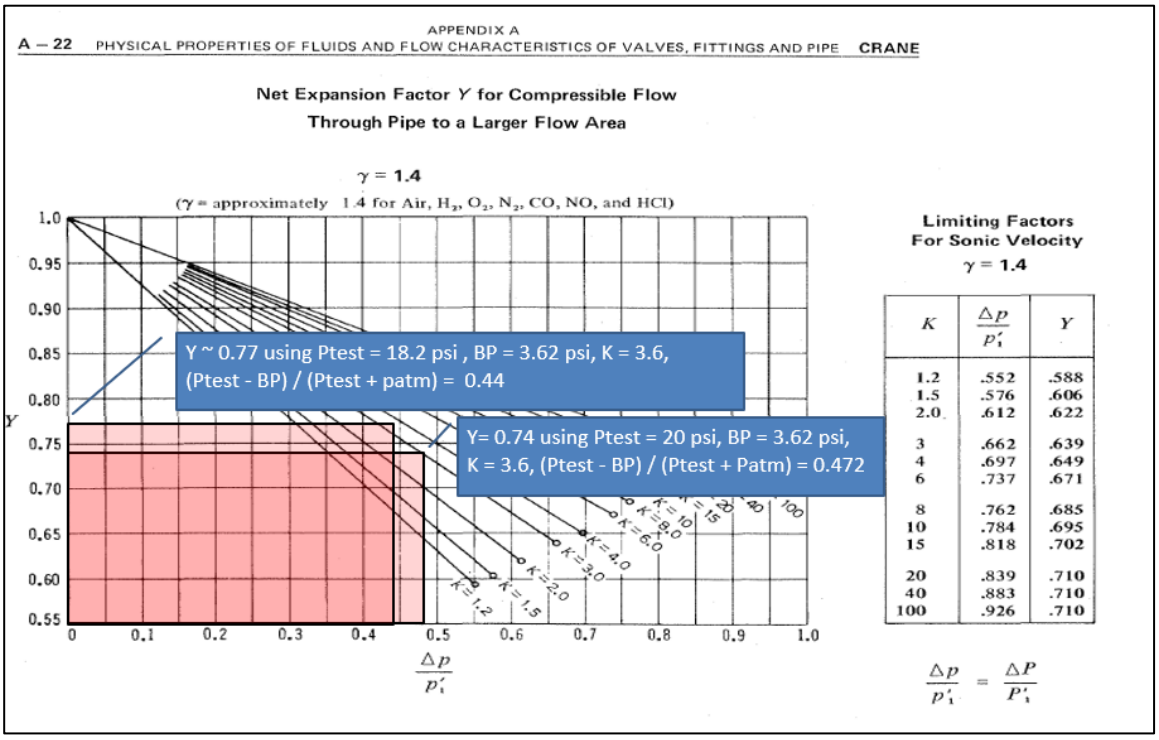
- Y = 0.75798 using $PDTP_{final}$ of 18.21 psi
- Y = 0.7426 using a starting test pressure of 20 psi

WesTech has previously used 0.74 in the past for the HFUG 2020AN module, which is more conservative as using a lower net expansion factor yields a lower ALCR and $LRV_{DIT.}$ The 0.74 was calculated as shown below:

$(P_{test}$ - BP) / (P_{test} + P_{atm}) =	**0.472**	Note: this value changes based on the Pressure Decay Test pressure
d_{fiber}	0.7 mm	HFUG Hollow-fiber lumen diameter (ID)
L	80 mm	Depth of membrane into potting material
f	0.0315	Friction factor (from iterative method), see "Iterative Method for DP" worksheet
Re	11,462	
K = f x (L/ d_{fiber}) =	**3.60**	Note: this value is fixed for all HFUG membrane systems
(Equation C.6 EPA Manual)		
Using the appropriate chart on page A22 or A23 (CRANE - Flow of Fluids) yields a value for Y as shown below:		
Y =	**0.74**	

$$Y \propto \left[\frac{1}{\left(\frac{P_{test} - BP}{P_{test} + P_{atm}} \right)}, K \right]$$

(Equation C.5 EPA Manual)



DIT Sensitivity

Sensitivity is defined as the maximum log removal value that can be reliably verified by the direct integrity test (i.e., LRV_{DIT}). The sensitivity of the direct integrity test establishes a maximum log removal credit that a membrane filtration process is eligible to receive if it is less than or equal to that demonstrated during challenge testing (i.e., $LRV_{C\text{-}Test}$). For example, if the challenge test demonstrated a $LRV_{C\text{-}Test}$ of 5.5 log, and the direct integrity test is capable of demonstrating an LRV_{DIT} of 4.5 log, the membrane filtration process would be eligible for removal credit up to 4.5 log. The sensitivity is related to the ability of the pressure sensor in terms of accuracy to measure a pressure decay rate. To evaluate the sensitivity of the pressure sensors in use for the DIT measurements, LRV_{DIT} is calculated using the accuracy of the pressure sensor to ensure the DIT is capable of demonstrating the log removal credited (LRC) for the membranes. In this evaluation, two conditions that needed to be met (and were met) as follows:

1. The smallest pressure decay rate measurable by the pressure sensor must be $\leq$ UCL
2. The LRV_{DIT} must be $\geq$ LRC where the LRC is $\leq LRV_{C\text{-}Test}$

LRC = 4.0-log ($< LRV_{C\text{-}Test}$)
$LRV_{C\text{-}Test}$ = 5.17 log (0.048 psi/min QCRV w/pressure decay test (NDPT))
LRV_{DIT} = 4.97-log (> LRC) which is the sensitivity of the DIT using MFGM equation 4.9 where,

Q_p = 65 gpm (maximum design feed flow through a filter unit)
ALCR = 21.488 (calculations shown above)
P_{atm} = 14.48 psi
V_{sys} = 55.6 gallons (210.45-L = 0.210 m^3)
VCF = 1
ΔP_{test} = 0.0039 psi/min (< 0.08 psi/min UCL) is the sensitivity of the Wika A-10 transmitter.

$$LRV_{DIT} = \log\left(\frac{Q_p \bullet ALCR \bullet P_{atm}}{\Delta P_{test} \bullet V_{sys} \bullet VCF}\right)$$

Note: 0.0039 psi/min is the smallest pressure decay rate measurable by the Rosemount 3051 pressure transmitter used to measure the pressure decay rate during a direct integrity test, which was determined using the pressure sensor manufacturer's stated accuracy (± 0.065% of span, BFSL), expressed as a % of span x the maximum span (0 – 30 psi) anticipated measurement range) divided by the DIT duration of 5 minutes. ΔP_{test} must be less than or equal to the UCL. In this case:

ΔP_{test} = [(0.065% Accuracy/100%) x 30 psi span] / 5 minute DIT duration = 0.0039 psi/min, which is less than the 0.04 psi/min UCL, **yielding an LRV_{DIT} of 4.2-log, which is still greater than the 4.0-log removal credit.**

$$LRV_{DIT} = \log \bullet \left(\frac{Q_p \bullet ALCR \bullet P_{atm}}{\Delta P_{test} \bullet V_{sys} \bullet VCF}\right)$$

(Equation 4.9 EPA Manual)

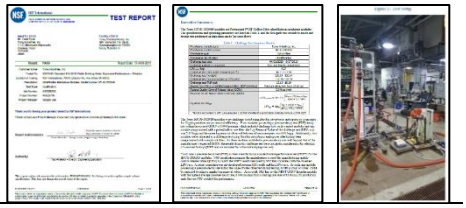
$Q_{p\ max}$	65.00	USgpm	
$ALCR_{DP}$	21.488	-	
P_{atm}	14.48	psia	
ΔP_{test}	0.0039	psi/min	Rosemount 3051 or equal with accuracy of (0.065%/100%) x 30 psi / 5 min = 0.0039 psi/min
V_{sys}	55.60	gallons	NEED HIGH END FOR MIT'S
VCF	1	-	
Note - WesTech used 0.021 psi/min, yielding 4.24 LRVDIT.			
$LRV_{Sensitivity\ DP=}$	4.97		The $LRV_{sensitivity}$ is the highest provable LRV using the Darcy-Pipe model

Appendix C
Membrane Module Product Specifications

Table C-1. Membrane Filter Module Specifications

Specification	Value
Membrane Manufacturer	Toray
Membrane Model Number	HFUG-2020AN
Challenge test standard (ANSI/NSF 419-YY, ETV, etc.)	NSF-419-18*, 40 CFR §141.719
Challenge test report date	August 15, 2019
$LRV_{C\text{-}Test}$	5.17-log (approved for 4.0-log = LRC)
Non-destructive performance test (NDPT)	Pressure decay test (10-min air hold time)
Quality Control Release Value (QCRV)	0.048 psi/min
OHA-DWS Challenge Study Verification Information	Date Verified = November 12, 2019 LRC = 4.0-log (*Giardia*/*Crypto*) Max Flux = 120 GFD @ 20°C Max TMP = 29 psi
Assumes a 2.98 psi maximum backpressure (BP_{max}) =>	Minimum DIT Pressure = 17.48 psi
ANSI/NSF Standard 61 certification (yes/no)	Yes
Membrane type (*e.g.*, hollow fiber, etc.)	Hollow fiber (14,000 fibers per module)
Number of fibers per module	14,000
Fiber inside (lumen) diameter	0.7 mm (1.1 mm outside diameter)
Fiber wall thickness	0.2 mm
Active fiber length (length of fibers not in potting)	71.5 Inches (1,816 mm) (module dimensions: 85 in x 8.5 in dia.)
Potting depth (or defect length)	80 mm potting depth
Darcy-Weisbach roughness coefficient (e)	0.75 µm (0.00075 mm)
Membrane classification (*e.g.,* ultra- or micro-filtration)	Ultrafiltration
Nominal membrane pore size (*e.g.*, 0.01 µm, etc.)	150,000 Daltons
Membrane material (*e.g.*, PVDF, polysulfone, etc.)	PVDF
Roughness coefficient	N/A
Feed side membrane filtration area (ft^2)	969 ft^2 (90 m^2) per module
Feed side volume (V_{sys}) Per Module	34-L (8.98 gallons) per module
Filtration flow direction (*i.e.*, inside-out or outside-in)	Outside-in
Hydraulic configuration (*i.e.*, deposition or suspension)	Deposition
Submerged or pressurized	Pressurized

*Testing of the Toray HFUG-2020AN Ultrafiltration (UF) membrane module was conducted in the NSF testing laboratory in 2019 to measure log removals of *Cryptosporidium*, using *Bacillus* endospores as a surrogate. The HFUG-2020AN is certified to NSF/ANSI Standard 61.



Product Datasheet

TORAY
Innovation by Chemistry

HFUG-2020AN

Pressurized Outside to In / Dead-end Filtration Ultrafiltration (UF) Membrane Module

The HFUG-2020AN module is Toray's latest UF innovation that features hollow fibers with a smaller diameter but with improved membrane durability and performance. The result is an increased surface area per module for more production output.

Membrane Characteristics	Unit	Value
Membrane Material		PVDF (Polyvinylidene fluoride)
Nominal Pore Size	µm	0.01
Outer Membrane Surface Area	m^2 (ft^2)	90 (969)
Operating Parameters	**Unit**	**Value**
Maximum Feed water / Filtrate Flow	m^3/h (gpm)	15 (66)
Maximum Backwash Flow	m^3/h (gpm)	16.8 (74)
Maximum Air Flow	Nm^3/h (scfm)	9.0 (5.3)
Maximum Inlet Pressure	kPa (psi)	300 (43.5)
Maximum Backwash Pressure	kPa (psi)	300 (43.5)
Normal Operating Trans-membrane Pressure	kPa (psi)	0–200 (0–29)
Operating Temperature Range	°C (°F)	1–40 (34–104)
pH Range – During Filtration		1–10
pH Range – During Cleaning		0–12

*Please contact Toray for operating manual and preliminary design, as capacity per module is highly dependent on feed water quality.

Product Certifications & Compliances

(Please contact Toray for details on the certified modules)

- NSF/ANSI/CAN 61 for drinking water applications
- NSF/ANSI 419 to comply with the U.S. EPA's Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), which allows membrane manufacturers to prove Cryptosporidium reduction
- Association of Membrane Separation Technology of Japan
- Korea Water and Wastewater Works Association

NSF

Applications

Drinking water, Industrial process water, Pretreatment for seawater RO desalination, Secondary and Tertiary wastewater

1 of 2

Product Datasheet

"TORAY"
Innovation by Chemistry

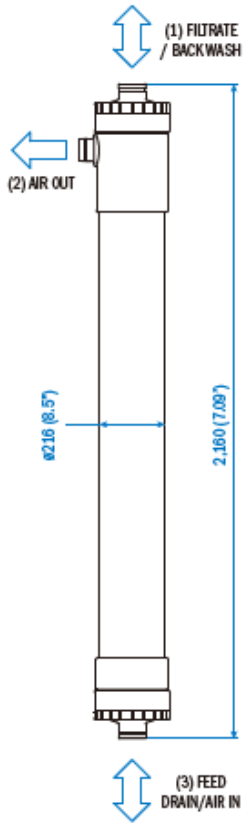
HFUG-2020AN

Pressurized Outside to In / Dead-end Filtration Ultrafiltration (UF) Membrane Module

Dimensions and Weight		Unit	Value
Diameter		mm (in)	216 (8.5)
Length		mm (ft)	2,160 (7.087)
Weight	Full of Water	kg (lbs)	92 (203)
	After Draining	kg (lbs)	49 (108)

Connections	Value
(1) Filtrate / Backwash	Housing type joint, 80A
(2) Air Out	Housing type joint, 65A
(3) Feed Drain / Air In	Housing type joint, 80A

Material Composition	
Casing	uPVC
Cap	uPVC
Potting	Epoxy resin
O-ring	EPDM



Please contact Toray for more detailed drawing and dimensions.

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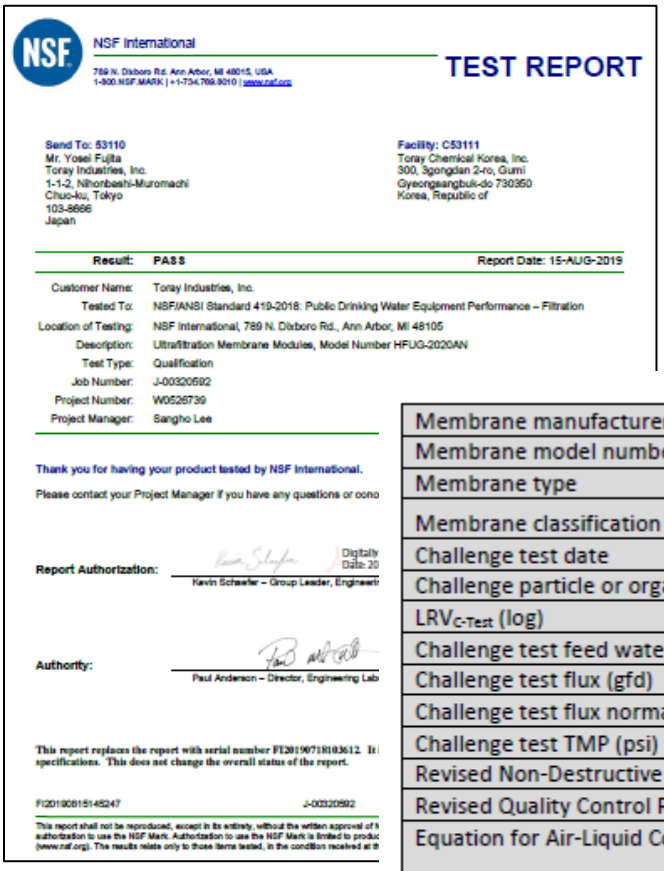
LinkedIn YouTube

For more info, please visit
water.toray

ANSI/NSF Standard 419-18 Challenge Study Report from the National Sanitation Foundation (NSF) dated August 15, 2019 (NSF job #J-00320592) for the installed Toray HFUG-2020AN membrane modules



NSF International

789 N. Dixboro Rd. Ann Arbor, MI 48015, USA
1-800.NSF.MARK | +1-734.769.8010 | www.nsf.org

TEST REPORT

Send To: 53110
Mr. Yosei Fujita
Toray Industries, Inc.
1-1-2, Nihonbashi-Muromachi
Chuo-ku, Tokyo
103-8666
Japan

Facility: C53111
Toray Chemical Korea, Inc.
300, 3gongdan 2-ro, Gumi
Gyeongsangbuk-do 730350
Korea, Republic of

Result: PASS — **Report Date:** 15-AUG-2019

Customer Name:	Toray Industries, Inc.
Tested To:	NSF/ANSI Standard 419-2018: Public Drinking Water Equipment Performance – Filtration
Location of Testing:	NSF International, 789 N. Dixboro Rd., Ann Arbor, MI 48105
Description:	Ultrafiltration Membrane Modules, Model Number HFUG-2020AN
Test Type:	Qualification
Job Number:	J-00320592
Project Number:	W0526739
Project Manager:	Sangho Lee

Thank you for having your product tested by NSF International.

Please contact your Project Manager if you have any questions or conc

Report Authorization: Digitally Date: 20
Kevin Schaefer – Group Leader, Engineeri

Authority:
Paul Anderson – Director, Engineering Lab

This report replaces the report with serial number FI20190718103612. It specifications. This does not change the overall status of the report.

FI20190815145247 J-00320592

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Table 1 – Challenge Test Summary Results

Membrane manufacturer	Toray Industries, Inc.
Membrane model number	HFUG-2020AN
Membrane type	Hollow fiber
Membrane classification	Ultrafiltration
Challenge test date	04/01/2019 – 6/27/2019
Challenge particle or organism	MS2 and *Bacillus atrophaeus*
$LRV_{C\text{-}Test}$ (log)	5.17
Challenge test feed water temperature (°C)	16.11 – 21.94
Challenge test flux (gfd)	120.14 - 120.57
Challenge test flux normalized to 20°C (gfd)[1]	113.78- 132.79
Challenge test TMP (psi)	15.19– 18.29
Revised Non-Destructive Performance Test (NDPT) Method	Pressure decay test from 18.85 psi
Revised Quality Control Release Value (QCRV)	0.048 psi/min
Equation for Air-Liquid Conversion Ratio (ALCR)	$ALCR_{Turbulent} = 170 \times Y \times \sqrt{\frac{(P_{test} - BP)(P_{test} + P_{atm})}{((460 + T) \times TMP)}}$
Equation for LRV_{DIT}	$LRV_{DIT} = \log_{10}\left[\frac{Q_P \times ALCR \times P_{atm}}{\Delta P_{test} \times V_{sys} \times VCF}\right]$

[1]Test flux normalized to 20°C using equation 2.10 from the Membrane Filtration Guidance Manual, USEPA 2005

A summary of the Toray HFUG-2020AN modules is shown below in Table 3.

Table 3 - Manufacturer and Model Specifications

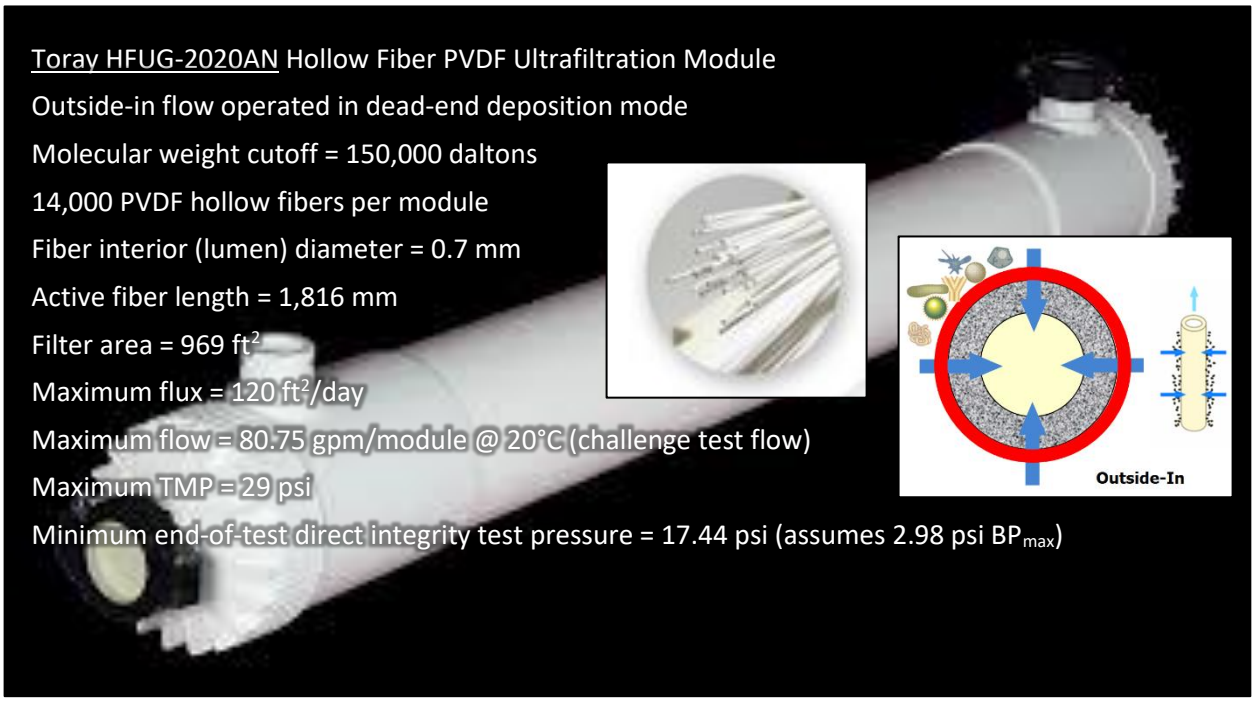
Description	
Membrane Make	Toray
Membrane Model Number	HFUG-2020AN
ANSI/NSF Standard 61 certification	Certified
Membrane type	Hollow Fiber
Membrane classification	Ultrafiltration
Nominal & max pore size, or molecular weight cutoff rating	150,000 daltons
Membrane media symmetry	-
Membrane material	PVDF
Feed side membrane filtration area (ft^2)	969
Membrane module specifications	
Module outside diameter (mm)	216
Length (mm)	2,160
Module volume (gallons and liters)	Feed side, lumen, end caps: 45.0 Liters, 11.88 gallons
Potting depth (mm)	-
Potting material	Epoxy and/or equivalent
Module weight – full/dry (kg)	110 / 67
Module casing material – if pressurized	PVC and/or equivalent
Membrane fiber characteristics	
Number of fibers per module	14,000
Inside fiber diameter (mm)	0.7
Fiber wall thickness (mm)	0.2
Active fiber length (mm)	1,816
Filtration Flow Direction (i.e., inside-out or outside-in)	Outside – In
Hydraulic configuration (i.e., deposition or suspension)	Dead End

Operating Limits	
Maximum design filtrate flux at 20°C (gfd)	120
Maximum inlet module pressure (psi)	43.5
Maximum design transmembrane pressure (TMP) at 20°C	43.5 psi max, 29.0 psi normal operation
Maximum TMP at any temperature	29 psi
Max oxidant tolerance (cleaning; oxidant(s))	3000 mg/L Cl_2
Max oxidant tolerance (normal operation; oxidant(s))	-
pH tolerance range (cleaning)	0.0 – 12.0 (0.0-40°C)
pH tolerance range (normal operation)	1.0 – 10.0 (0.0 – 40°C)
Temperature tolerance range	0.0 – 40°C

Table 21 - Membrane Integrity Summary Information

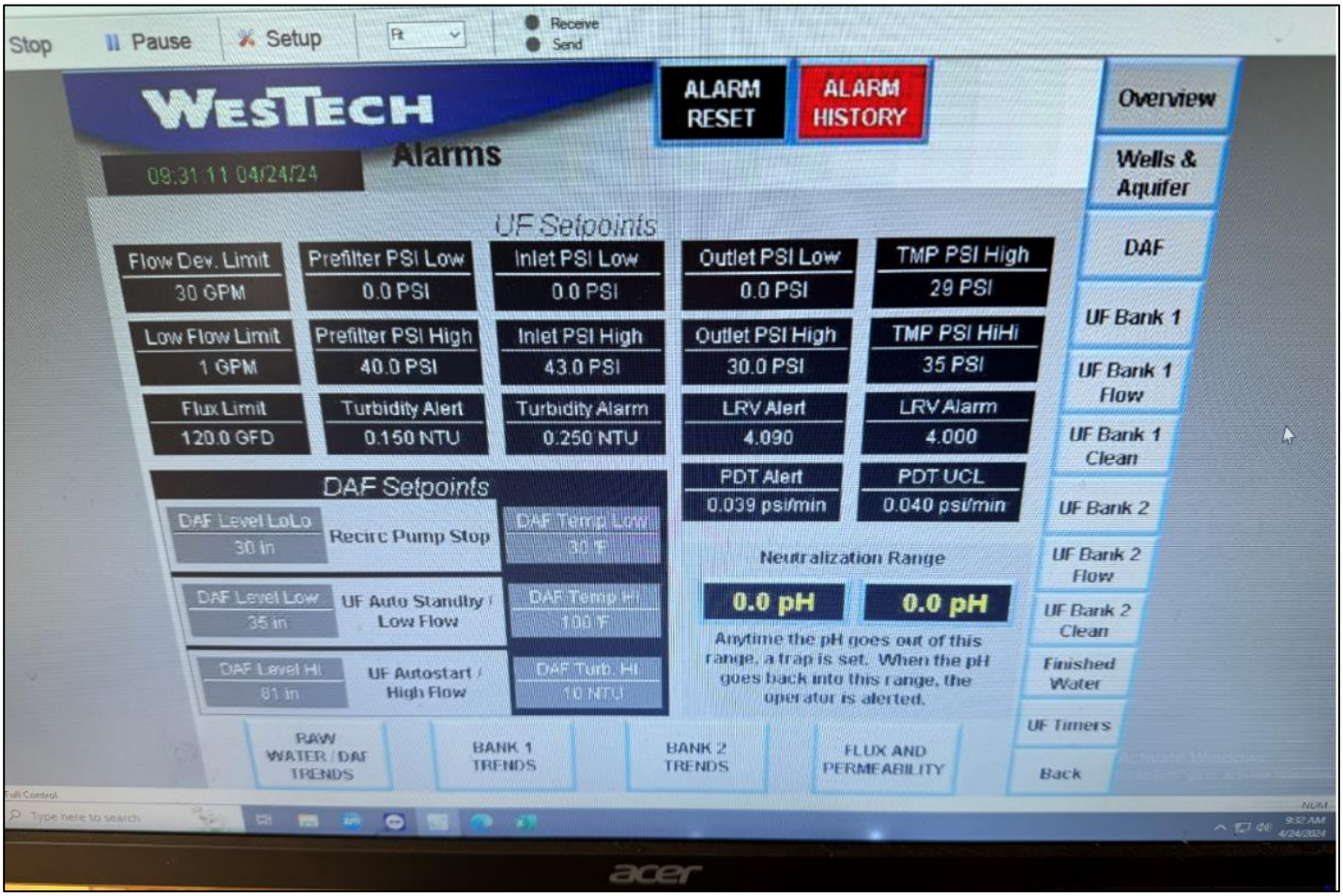
Revised NDPT method and QCRV	
NDPT method (e.g., pressure decay, etc.)	**10-minute pressure decay from 18.85 psi**
QCRV (include units)	**0.048 psi/min**
Equations for use in determining LRV_{DIT}, ALCR, and DIT pressures	
LRV_{DIT} equation	$LRV_{DIT} = \log_{10}\left[\frac{Q_P \times ALCR \times P_{atm}}{\Delta P_{test} \times V_{sys} \times VCF}\right]$
ALCR equation	$ALCR_{Turbulent} = 170 \times Y \times \sqrt{\frac{(P_{test} - BP)(P_{test} + P_{atm})}{((460 + T) \times TMP)}}$
DIT pressure equation	$P_{test} = (0.193 \times K \times \sigma \times cos\theta) + BP_{max}$
Constants for use in determining LRV_{DIT}, ALCR, and DIT pressures	
Volume of pressurized air in module during DIT (liters)	34.0
Volumetric concentration factor (VCF, dimensionless)	1
Net expansion factor (Y)	0.588
Lumen diameter (d, mm)	1.1 outside, 0.7 inside
Potting depth or defect length (l, mm)	-
Pore shape correction factor (K, dimensionless)	1
Liquid membrane contact angle (ɵ, degrees)	0°
Maximum design flow rate per module (L/min)	305.67

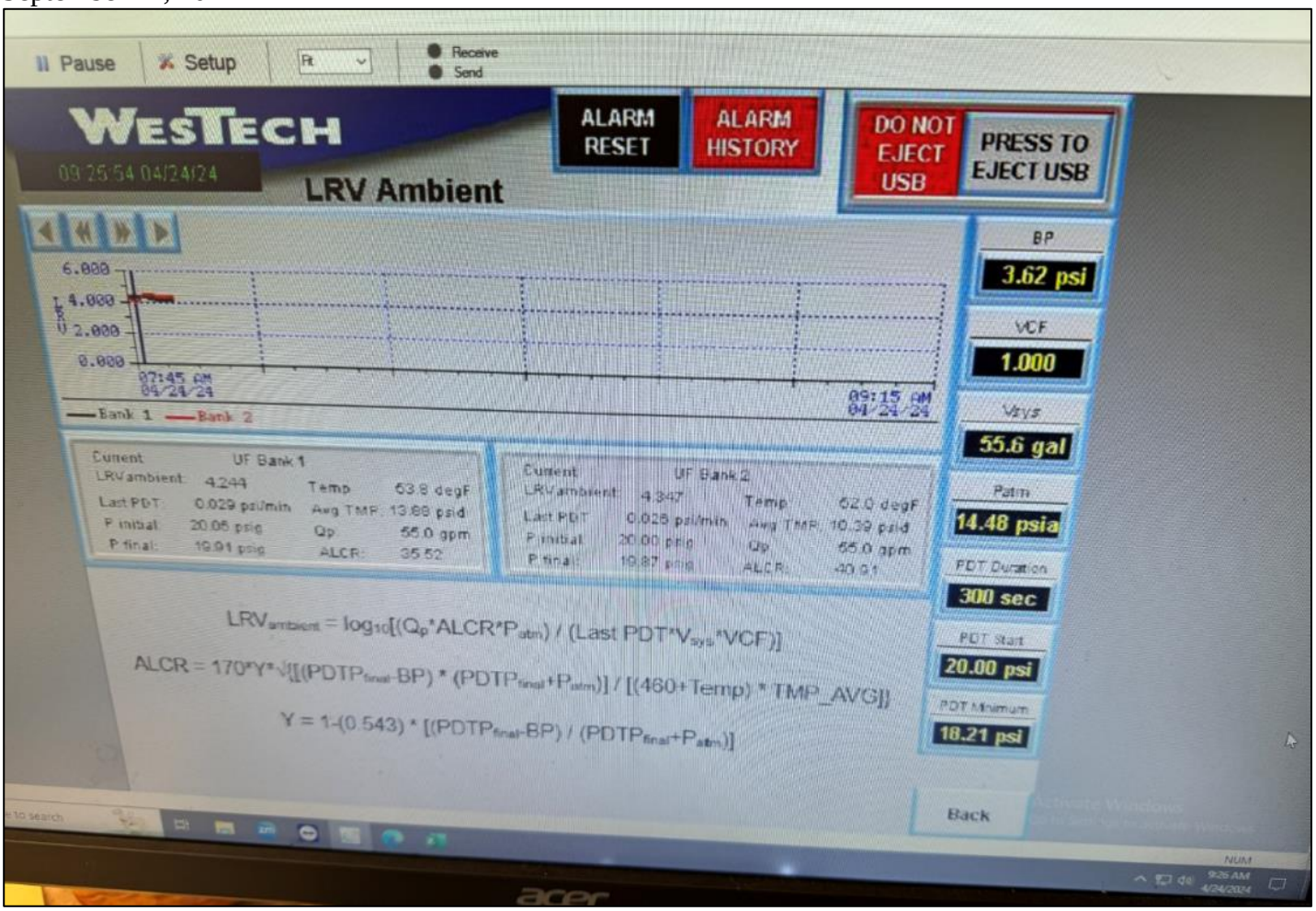
Note: The "revised" nondestructive performance test (NDPT) method and quality control release value (QCRV) are the NDPT and QCRV established as a result of the challenge study that will demonstrate meeting the 3 μ resolution requirement (with calculations and variables used) and that the modules will meet the removal efficiency demonstrated by the challenge test ($LRV_{C\text{-}Test}$). These may not have changed from what the manufacturer was already using, however, the term "revised" is used to denote the NDPT and QCRV reviewed/revised as a result of the challenge test.



Appendix D

SCADA Screens and PLC Programming from 4/24/24

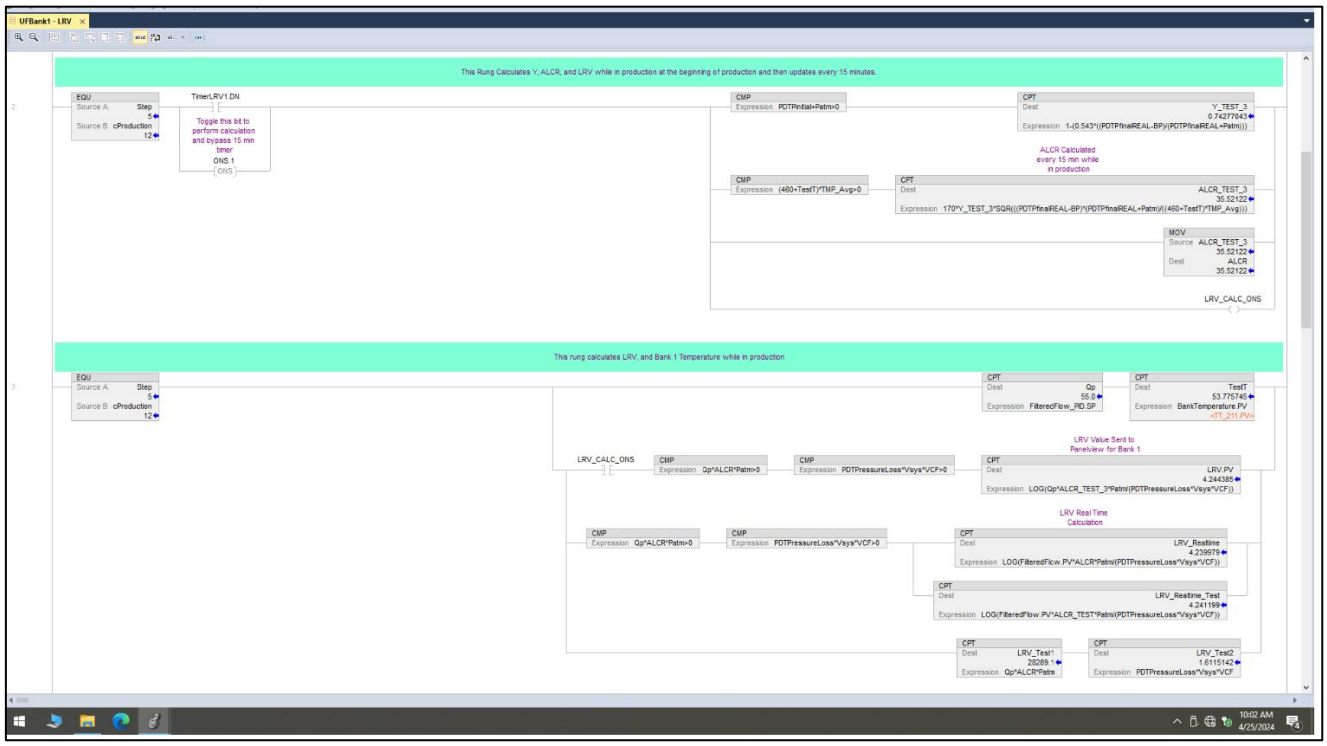




$$LRV_{ambient} = \log_{10}[(Q_p * ALCR * P_{atm}) / (Last\ PDT * V_{sys} * VCF)]$$

$$ALCR = 170 * Y * \sqrt{\{[(PDTP_{final} - BP) * (PDTP_{final} + P_{atm})] / [(460 + Temp) * TMP\_AVG]\}}$$

$$Y = 1 - (0.543) * [(PDTP_{final} - BP) / (PDTP_{final} + P_{atm})]$$



CPT
Dest Y_TEST_3
0.74277043
Expression 1-(0.543*((PDTPfinalREAL-BP)/(PDTPfinalREAL+Patm)))

ALCR Calculated every 15 min while in production

CPT
Dest ALCR_TEST_3
35.52122
Expression 170*Y_TEST_3*SQR(((PDTPfinalREAL-BP)*(PDTPfinalREAL+Patm)/((460+TestT)*TMP_Avg)))

MOV
Source ALCR_TEST_3
35.52122
Dest ALCR
35.52122

LRV Real Time Calculation

CPT
Dest LRV_Realtime
4.239979
Expression LOG(FilteredFlow.PV*ALCR*Patm/(PDTPressureLoss*Vsys*VCF))