PUBLIC HEALTH DIVISION
Drinking Water Services
Tina Kotek, Governor

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November 9, 2023

John Gastineau,
Sites and Facilities Manager
Young Life
PO Box 220
Antelope, OR 97001
jgastineau@wfr.younglife.org

Letter sent only via e-mail

Re: Young Life (PWS ID#01246)
Membrane Module Replacement with 8 Toray HFUG-2020AN Modules
Final Approval – PR# 75-2021

Dear Mr. Gastineau:

Thank you for submitting information via e-mail on October 31, 2023, addressing the conditions in my Conditional Approval letter dated July 16, 2021. **The project regarding the installation of 8 new Toray HFUG-2020AN membrane modules (4 in each of two WesTech AP-VI filtration skids) is granted Final Approval. See Table 1 for pathogen removal credits and Table 2 for operating conditions**.

Project summary:
The project involved replacing the 8 existing Toray HFS-2020 membrane modules (originally installed in 2013 with 4 modules per skid in two WesTech AP-VI filtration skids having a capacity of up to 6 modules per skid) with a total of 8 new Toray HFUG-2020AN ultrafiltration PVDF hollow fiber membrane modules (4 modules per skid).

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

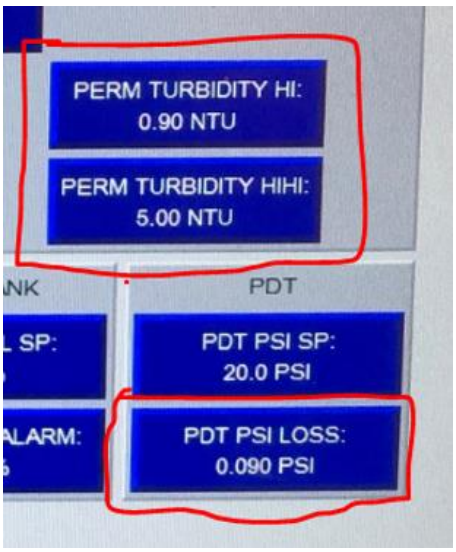
Operating Parameter	Limit
Direct integrity test (DIT) frequency	**Conduct at least 1 DIT each day of operation**
DIT duration/hold time	5 minutes
DIT starting test pressure	**20 psi**
Minimum allowed DIT pressure	**18.21** psi throughout the DIT duration (starting test pressure is anticipated to be 20 psi)
Maximum allowable pressure decay rate (PDR) upper control limit (UCL)	**UCL = 0.08 $^{psi}/_{min}$**
Minimum DIT pressure transducer accuracy for the established UCL[1]	**± 0.5% of span (0-50 psi), 0.05 psi/min (equal to the stated accuracy of the Wika-A10 pressure transducer installed).**
Membrane Minimum Performance ($LRV_{ambient}$)	**$LRV_{ambient}$ = 4.0-log (must be ≥ 4.0-log LRC)**
DIT Sensitivity (LRV_{DIT})	**4.2-log_{10} at PDR = 0.05 $^{psi}/_{minute}$ and flow of 115.9 gpm**. (4.0-log at PDR = 0.08 psi/min and flow of 115.9 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
Maximum allowed filtrate flux [gfd]	**120 $^{gal/SqFt}/_{day}$** @ 20°C. This max flux yields a peak plant production of **323 gpm using 4 out of 6 possible modules per skid** (**80.75 gpm/module**). 115.9 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.

It is noted that on the alarm setpoints SCADA screen, on the lower right, there is a box that says "PDT PSI LOSS 0.090 **PSI**". That is actually the 0.090 **psi/min** loss rate setpoint, and you have verified that this triggers an alarm correctly and is just mislabeled. It is on scheduled for correction in the spring. Also note that **the 0.09 psi/min decay rate set point should be changed to 0.08 psi/min** as 0.09 psi/min is based on a sustained starting test pressure of 20 psi as shown in the calculations in Appendix B of this letter. Additionally, the $LRV_{ambient}$ calculation programmed into SCADA uses a maximum backpressure (BP_{max}) of 3.2 psi (88.7 inches of water). The original calculations showed a BP_{max} of 3.62 psi (100.3 inches of water). **Please let me know what the verified value for BP_{max} should be and make corrections to the PLC programming accordingly.**



Also **consider setting the permeate turbidity high-high alarm to 0.15 NTU** rather than 0.90 NTU **and the high alarm to 0.05 NTU** rather than 5.00 NTU as regulatory and optimal set points, respectively.

This 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.

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

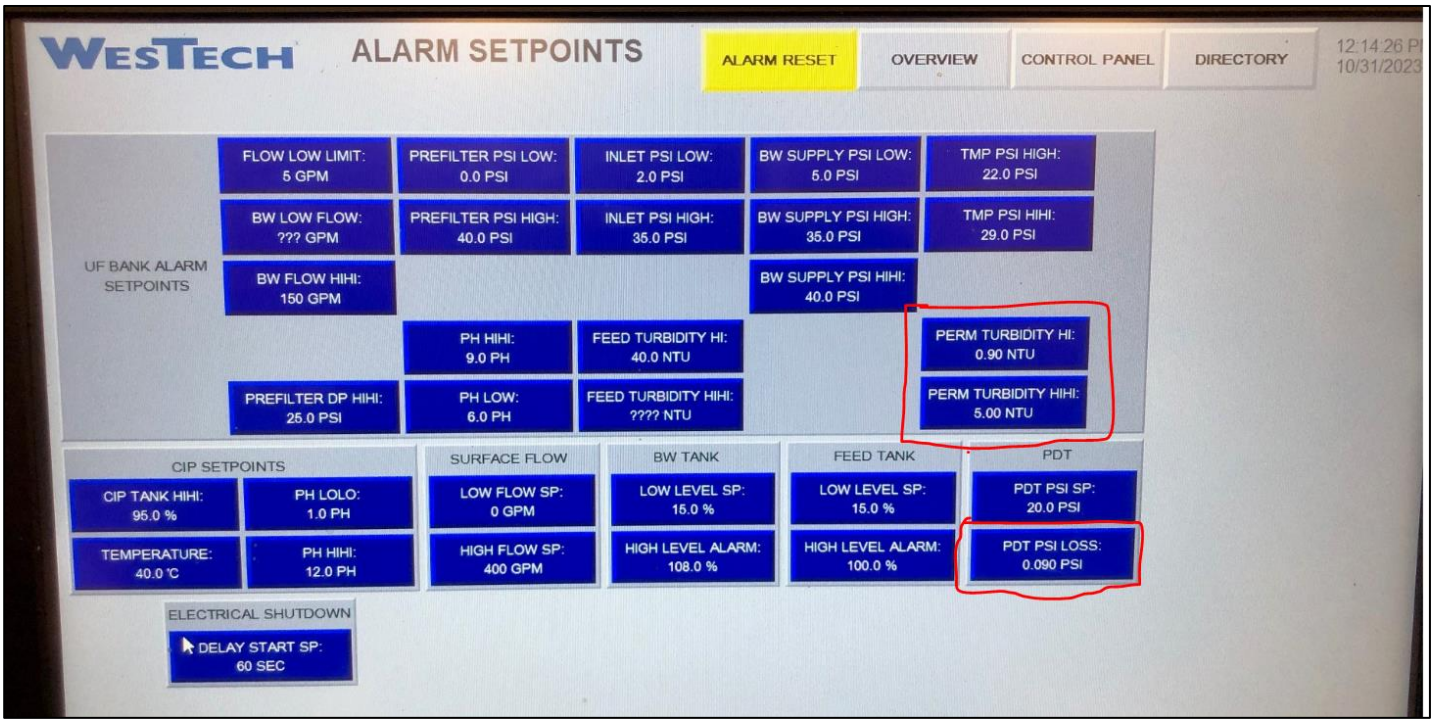
cc. Chantal Wickstrom (Chantal.T.Wikstrom@oha.oregon.gov)

Project Description:

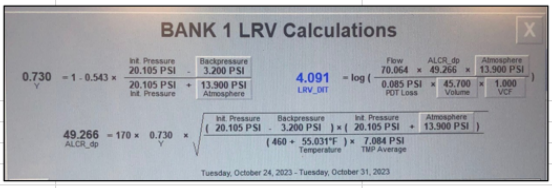
On May 12, 2021, our office received information on a project to replace the 8 existing Toray HFS-2020 membrane modules originally installed in 2013 (4 modules per skid in two WesTech AP-VI filtration trains with capacity for up to 6 modules each) with a total of 8 Toray HFUG-2020AN ultrafiltration PVDF hollow fiber membrane modules (4 modules per skid). A plan review fee of $248 was also received on May 12, 2021, and a Conditional Approval letter was issued July 16, 2021

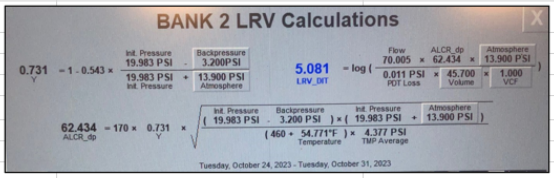
UF Skid 1

UF Skid 2



Verification of SCADA LRV calculations & comparison of variables used in plan review	Bank 1 SCADA Screen 10/31/23	Bank 2 SCADA Screen 10/31/23	Conditional Approval LTR 7/16/21	Final Approval LTR 11/9/23	Test Bank 1 w/Bank 2 PDR (0.011 psi/min)
Ptest, psi	20.105	19.983	20.000	18.210	20.105
BPmax, psi	3.20	3.20	3.62	3.62	3.20
Patm, psi	13.9	13.9	14.7	13.9	13.9
(Ptest - BP)/(Ptest + Patm) =	0.49713	0.49532	0.47205	0.45438	0.49713
Y =	**0.730**	**0.731**	**0.740**	**0.740**	**0.730**
Ptest, psi	20.11	19.98	20.00	18.21	20.11
BPmax, psi	3.20	3.20	3.62	3.62	3.20
Patm, psi	13.9	13.9	14.7	13.9	13.9
Tactual, °F	55.031	54.771	57.200	57.200	55.031
TMPactual, psi	7.084	4.377	29.000	29.000	7.084
Y	0.730	0.731	0.740	0.740	0.730
ALCR =	**49.264**	**62.434**	**24.489**	**22.233**	**49.264**
Qp actual, gpm	70.064	70.005	115.900	115.900	70.064
Actual ALCRDP	49.26	62.43	24.49	22.23	49.26
Patm, psi	13.9	13.9	14.7	13.9	13.9
Δptest, psi/min	0.085	0.011	0.090	0.080	0.011
Vsys, gallons	45.70	45.70	45.71	45.71	45.70
VCF	1	1	1	1	1
LRV (log_{10}) =	**4.092**	**5.082**	**4.0**	**4.0**	**4.980**
LRC, log	4.00	4.00	4.00	4.00	4.00
UCL (psi/min) =			**0.09**	**0.08**	

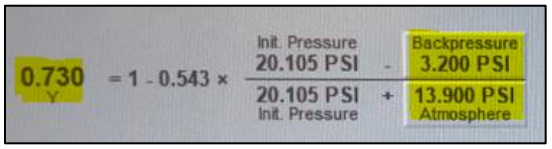




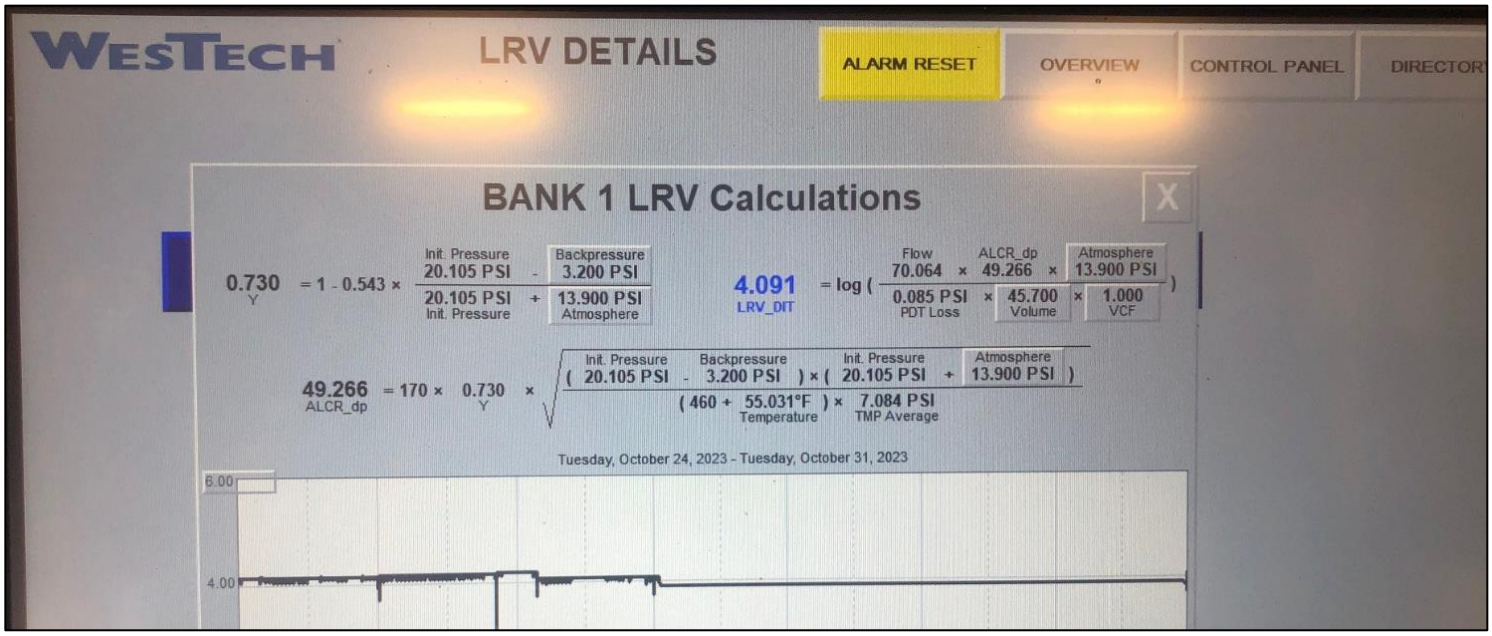
$$ALCR_{DP} = 170 \bullet Y \bullet \sqrt{\frac{(P_{test} - BP) \bullet (P_{test} + P_{atm})}{(460 + T) \bullet TMP}}$$

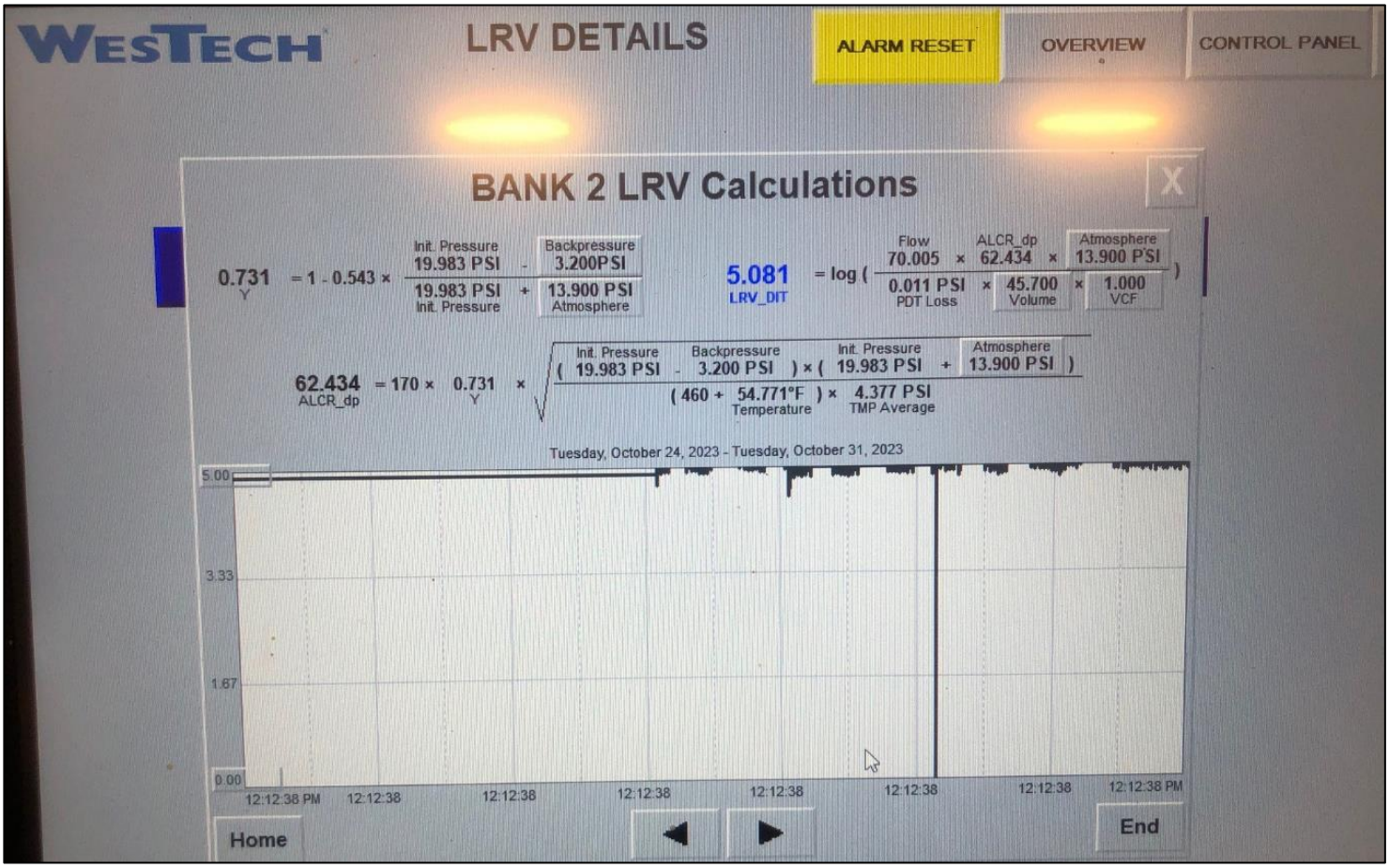
$$LRV_{DIT} = \log \bullet \left(\frac{Q_p \bullet ALCR \bullet P_{atm}}{\Delta P_{test} \bullet V_{sys} \bullet VCF} \right)$$

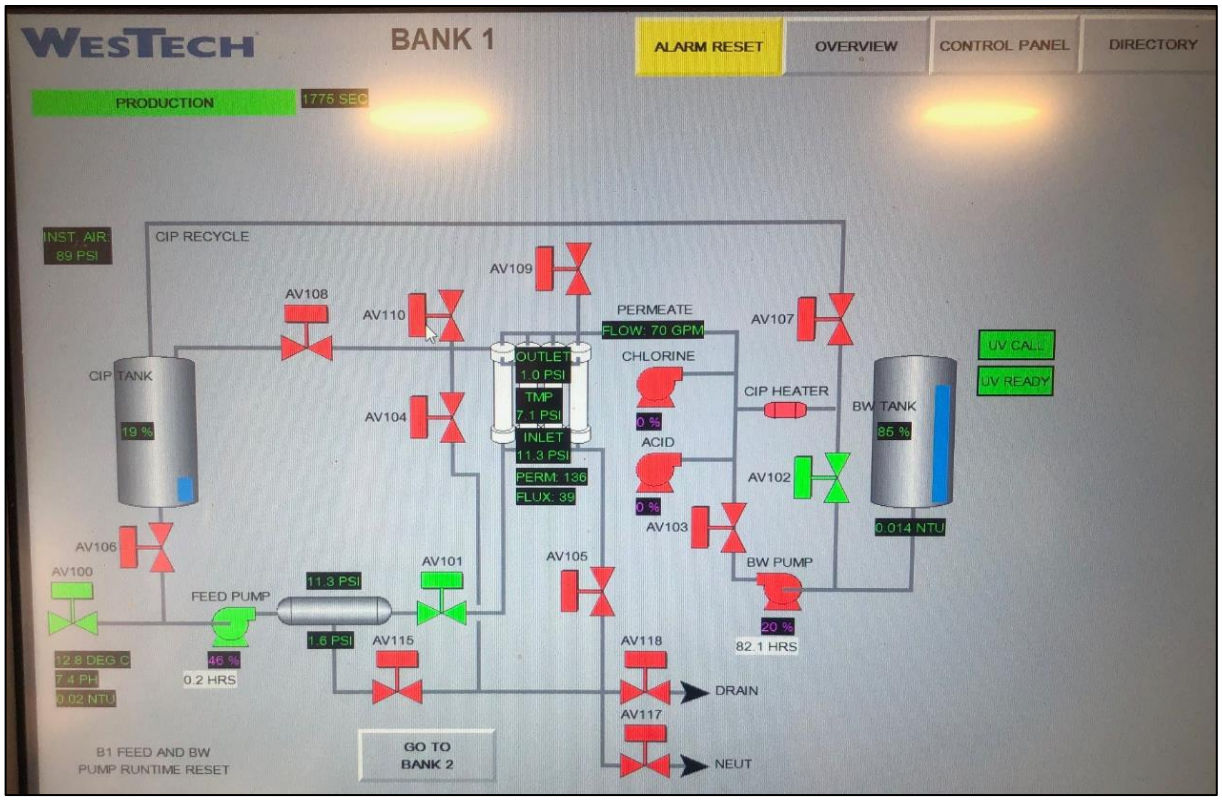
$$UCL = \frac{Qp \bullet ALCR \bullet P_{atm}}{10^{LRV} \bullet V_{sys} \bullet VCF}$$

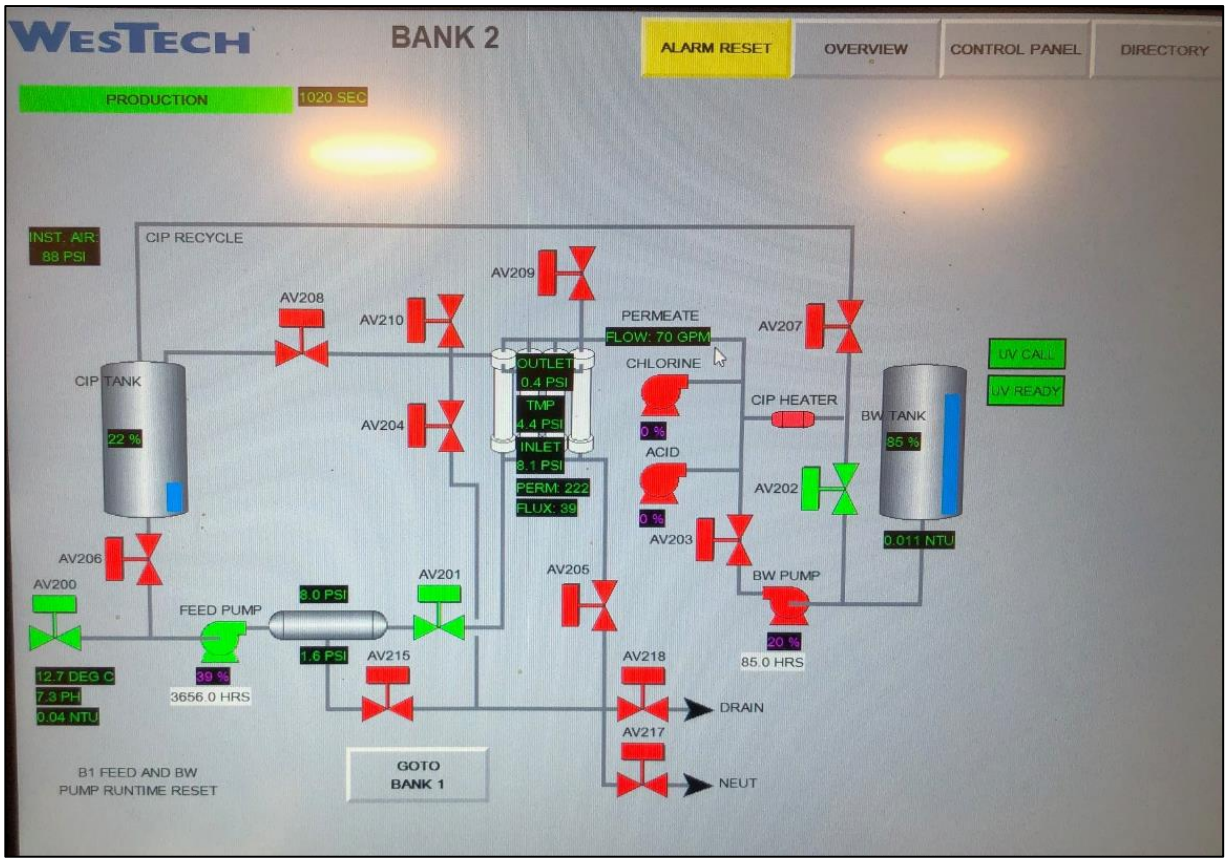


Note: Calculations done for the Conditional Approval letter used an atmospheric pressure (P_{atm}) of 14.7 psi (pressure at sea level), however, the 13.9 psi (1,550-ft above sea level) that is currently programmed into the PLC is more appropriate for the location of the plant. The difference in LRV using a net expansion factor (Y) of 0.74 versus 0.73 is negligible. As previously mentioned, the backpressure needs to be verified (is it 3.62 psi or is it 3.2 psi?)


WESTECH
LRV DETAILS
ALARM RESET
OVERVIEW
CONTROL PANEL
DIRECTOR
BANK 1 LRV Calculations
0.730 = 1 - 0.543 × (Init. Pressure 20.105 PSI - Backpressure 3.200 PSI) / (20.105 PSI + 13.900 PSI)
4.091 LRV_DIT = log (Flow 70.064 × ALCR_dp 49.266 × Atmosphere 13.900 PSI / 0.085 PSI PDT Loss × 45.700 Volume × 1.000 VCF)
49.266 ALCR_dp = 170 × 0.730 Y × √ (20.105 PSI - 3.200 PSI) × (20.105 PSI + 13.900 PSI) / (460 + 55.031°F Temperature) × 7.084 PSI TMP Average
Tuesday, October 24, 2023 - Tuesday, October 31, 2023
6.00
4.00


WESTECH
LRV DETAILS
ALARM RESET
OVERVIEW
CONTROL PANEL
BANK 2 LRV Calculations
0.731 = 1 - 0.543 × (Init. Pressure 19.983 PSI - Backpressure 3.200PSI) / (19.983 PSI + 13.900 PSI)
5.081 LRV_DIT = log (Flow 70.005 × ALCR_dp 62.434 × Atmosphere 13.900 PSI / 0.011 PSI PDT Loss × 45.700 Volume × 1.000 VCF)
62.434 ALCR_dp = 170 × 0.731 Y × √ (19.983 PSI - 3.200 PSI) × (19.983 PSI + 13.900 PSI) / (460 + 54.771°F Temperature) × 4.377 PSI TMP Average
Tuesday, October 24, 2023 - Tuesday, October 31, 2023
5.00
3.33
1.67
0.00
12:12:38 PM
12:12:38
12:12:38
12:12:38
12:12:38
12:12:38
12:12:38
12:12:38 PM
Home
End


WESTECH
BANK 1
ALARM RESET
OVERVIEW
CONTROL PANEL
DIRECTORY
PRODUCTION
1775 SEC
INST. AIR
89 PSI
CIP RECYCLE
AV109
AV108
AV110
PERMEATE
FLOW: 70 GPM
AV107
UV CALL
UV READY
CIP TANK
19 %
OUTLET
1.0 PSI
TMP
7.1 PSI
INLET
11.3 PSI
PERM: 136
FLUX: 39
CHLORINE
0 %
CIP HEATER
BW TANK
85 %
AV104
ACID
0 %
AV102
AV103
0.014 NTU
AV106
AV100
AV101
AV105
BW PUMP
FEED PUMP
11.3 PSI
1.6 PSI
AV115
AV118
20 %
82.1 HRS
12.8 DEG C
7.4 PH
0.02 NTU
46 %
0.2 HRS
DRAIN
AV117
B1 FEED AND BW
PUMP RUNTIME RESET
GO TO
BANK 2
NEUT


WESTECH
BANK 2
ALARM RESET
OVERVIEW
CONTROL PANEL
DIRECTORY
PRODUCTION
1020 SEC
INST. AIR
88 PSI
CIP RECYCLE
AV209
AV208
AV210
PERMEATE
FLOW: 70 GPM
AV207
UV CALL
UV READY
CIP TANK
22 %
OUTLET
0.4 PSI
TMP
4.4 PSI
INLET
8.1 PSI
PERM: 222
FLUX: 39
CHLORINE
0 %
CIP HEATER
BW TANK
85 %
AV204
ACID
0 %
AV202
AV203
0.011 NTU
AV206
AV200
AV201
AV205
BW PUMP
FEED PUMP
8.0 PSI
1.6 PSI
AV215
AV218
20 %
85.0 HRS
12.7 DEG C
7.3 PH
0.04 NTU
39 %
3656.0 HRS
DRAIN
AV217
B1 FEED AND BW
PUMP RUNTIME RESET
GOTO
BANK 1
NEUT

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) in $^{psi}/_{min}$
  Every membrane system has an Upper Control Limit (UCL) measured in $^{psi}/_{min}$. The UCL 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 = 13.9 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 = 45.71 gallons (173 liters = 0.173 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
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 = 13.9 psi (same for $LRV_{ambient}$)
BP, Backpressure during the DIT [psi]	Constant[3] = 3.62 psi = 100.28 inches of water.
P_{Test} used for ΔP_{eff} equation [psi]	Constant[4] = 18.21 psi
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]	Constant = 0.74[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 3.2 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
[5] PLC programming is using the net expansion factor of 0.73, which is calculated using P_{test} = 20 psi, rather than 18.21 psi. However, the impact is a difference in LRV of 0.01-log, which is considered negligible.

The Upper Control Limit (UCL) is the maxium pressure decay rate 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 Young Life's two WesTech UF AltaPac (AP-VI) membrane filter units containing 4 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]	$\frac{527 \bullet \Delta P_{ref} \bullet (175 - 2.71 \bullet T + 0.0137 \bullet T^2)}{TMP \bullet (460+T)}$	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]	$\frac{527 \bullet \Delta P_{ref} \bullet (175 - 2.71 \bullet T + 0.0137 \bullet T^2)}{TMP \bullet (460+T)}$	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} = 18.21 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 0°C
θ = 0 degrees (0 radians), liquid-membrane contact angle
BP_{max} = 3.62 psi (100.28 inch 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). A D_{base} of 0.0002 psi/min (0.01 psi/5 min) was provided, but deemed negligible and not accounted for in this determination.

Upper Control Limit (UCL) in psi/minute

UCL = 0.08 psi/min w/ALCR = 22.51 (0.09 psi/min using ALCR = 24.49) is the maximum allowable pressure decay rate for the direct integrity test as calculated using MFGM equation 4.17 where,

Q_p = 115.9 gpm
P_{atm} = 13.9 psi
LRC = 4.0 log
V_{sys} = 45.71 gallons (173-L = 0.173 m^3)
VCF = 1

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

ALCR = 22.233 (24.205 using P_{test} = 20 psi) calculated using MFGM equation C.4 for turbulent flow through a breach in hollow fiber membranes where.

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

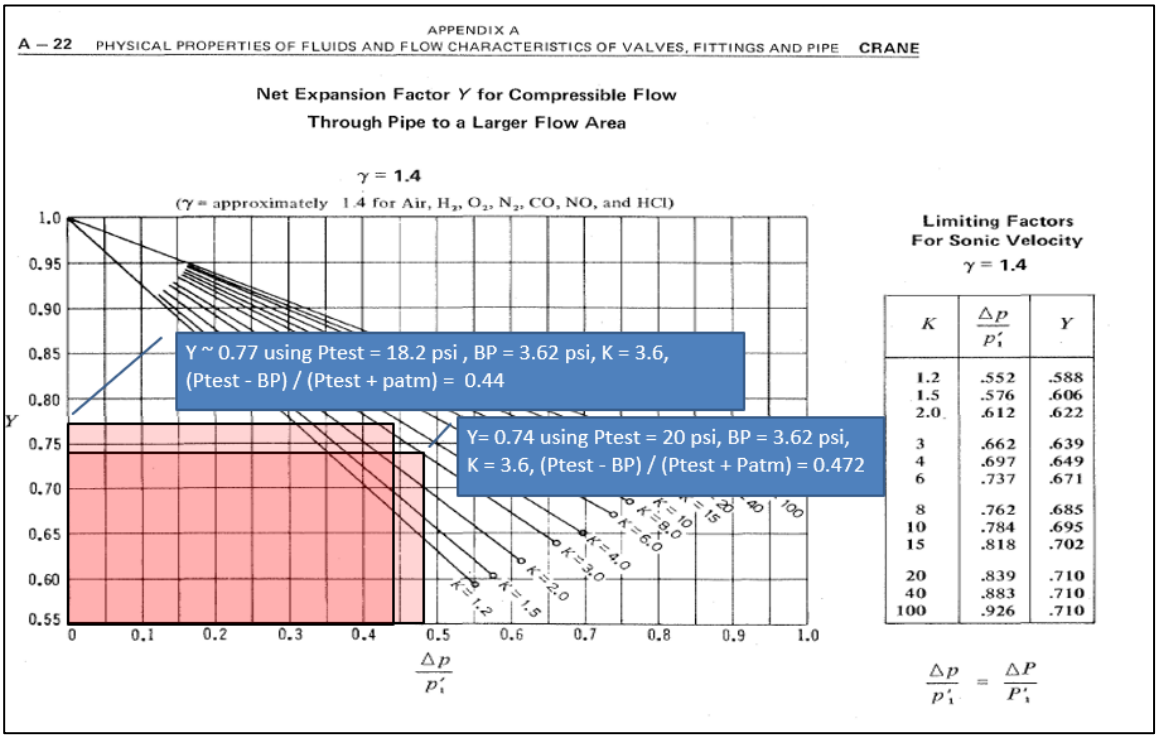
P_{test} = 18.2 psi (WesTech used 20 psi)
T = 57.2°F
TMP = 29.0 psi
BP = 3.62 psi (BP_{max})
P_{atm} = 13.9 psi
(P_{test} – BP) / (P_{test} + P_{atm}) = 0.4543 (0.4832 using P_{test} of 20 psi)
Y = 74

Using a lower net expansion factor yields a lower ALCR and LRV_{DIT}, therefore using Y = 74 as in the LRV calculations provided by WesTech is acceptable.

(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} = 4.2-log (> LRC) which is the sensitivity of the DIT using MFGM equation 4.9 where,

Q_p = 115.9 gpm (maximum design feed flow through a filter unit)
ALCR = 22.233 (calculations shown above)
P_{atm} = 13.9 psi
V_{sys} = 45.71 gallons (173-L = 0.173 m^3)
VCF = 1
ΔP_{test} = 0.05 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: 0.05 psi/min is the smallest pressure decay rate measurable by the Wika A-10 pressure trasmitter used to measure the pressure decay rate during a direct integrity test, which was determined using the pressure sensor manufacturer's stated accuracy (± 0.5% of span, BFSL), expressed as a % of span x the maximum span (0 – 50 psi) anticipated measurement range) divided by the DIT duration in minutes. ΔP_{test} must be less than or equal to the UCL. In this case:

ΔP_{test} = [(0.5% Accuracy/100%) x 50 psi span] / 5 minute DIT duration = 0.05 psi/min, which is less than the 0.08 psi/min UCL. (0.05 psi/min is 37.5% below the 0.08 psi/min UCL), **yielding an LRV_{DIT} of 4.2-log, which is still greater than the 4.0-log removal credit.**

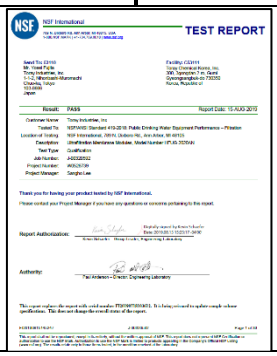
Appendix C

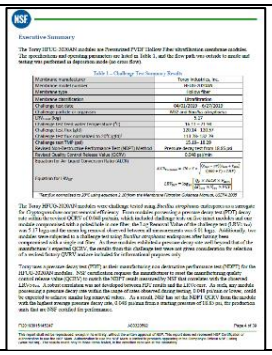
Membrane Module product Specifications

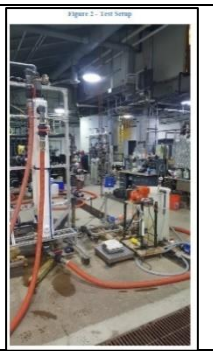
Table C-1. Membrane Filter Module Specifications

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)
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)	95 mm potting depth
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
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.


NSF International
TEST REPORT


Executive Summary



■ 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
	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

Product Datasheet

TORAY
Innovation by Chemistry

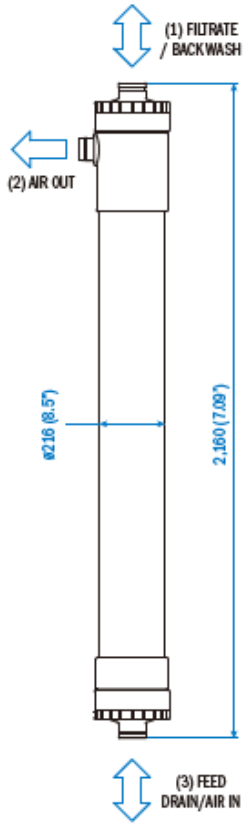
HFUG-2020AN

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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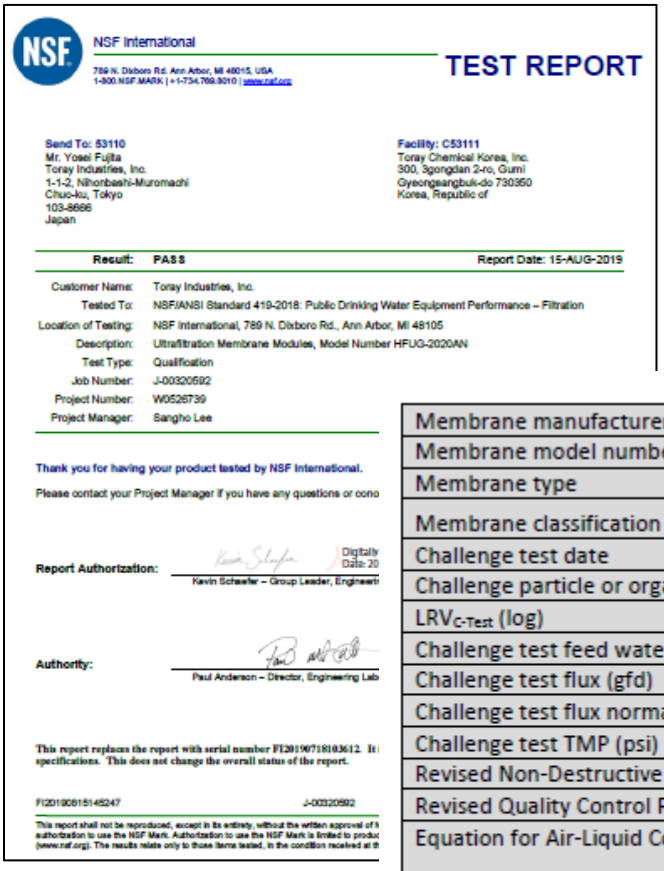
For more info, please visit
water.toray

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 48105, USA
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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 FI2019071810361 2. It specifications. This does not change the overall status of the report.

FI2019081545247 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 (e, 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.