PUBLIC HEALTH DIVISION
Drinking Water Services
Tina Kotek, Governor

Oregon Health Authority

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August 23, 2023

Matt Del Moro, PE
Project Engineer
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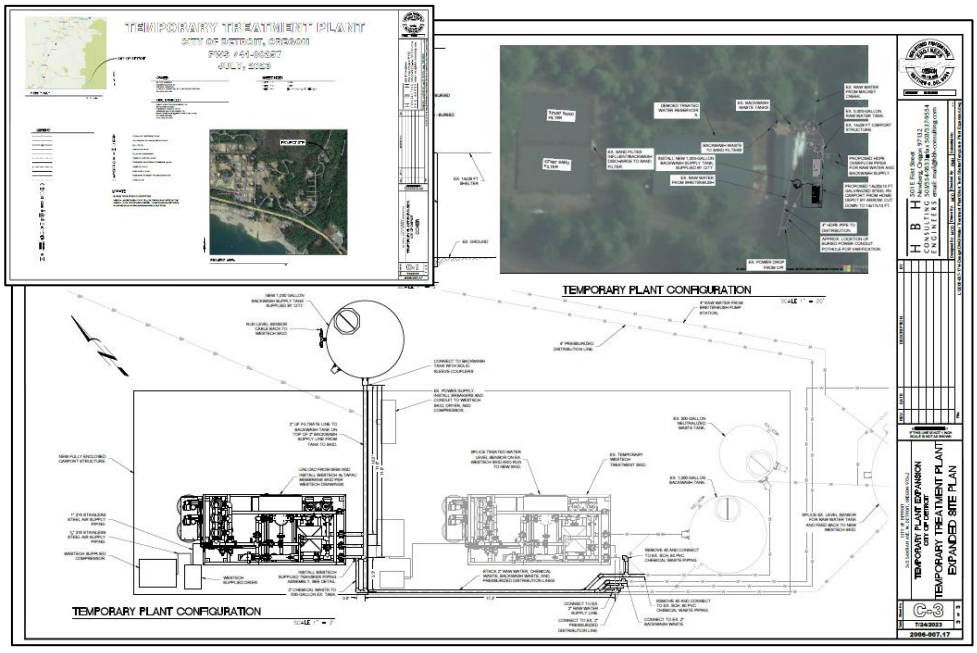
HBH Consulting Engineers, Inc.
501 First Street
Newberg, OR 97132

Sent via email

Re: 2nd 70-GPM WesTech UF Skid w/3 Toray HFUG-2020AN Modules (PR#111-2023)
Detroit Water System (PWS ID#00257)
Conditional Approval

Dear Mr. Del Moro:

Thank you for your submittal to the Oregon Health Authority's Drinking Water Services (DWS) of plan review information for the temporary membrane treatment plant for Detroit Water System. On August 10, 2023, our office received plans for a 2nd 70-GPM WesTech AltaPac APIII filter skid with three (3) Toray HFUG-2020AN ultrafiltration membrane modules, identical to the treatment skid approved in 2021 under plan review (PR) # 180-2020. A plan review fee of $285 was received on August 18, 2023 and the project was assigned PR# 111-2023.



The project includes installation of a temporary water treatment plant to serve a reduced number of connections (less than 300) in the Detroit Water System. This new 70-gpm treatment plant will augment the existing 70-gpm UF filter system that was installed after the fires in 2020, giving a total capacity of 140-gpm. Long term, another treatment plant will be built to serve a larger population. This new system will be housed in a secure, but temporary storage shelter and will utilize the existing clearwell used for disinfection contact time.

The temporary membrane treatment plant is granted 4.0-log removal of *Giardia* and 4.0-log removal of *Cryptosporidium*. The water system must meet the 4-log inactivation of viruses through appropriate contact time with chlorine at the entry point (i.e., after the treatment plant, prior to the first user). 4.0-log virus inactivation can be achieved by providing the 0.5-log inactivation of *Giardia* required post-filtration. **New monthly reporting forms are available for membrane filtration plants.** These forms will also use the 0.5-log inactivation column in the CT tables when filling out the CT required column.

Because the water system is using the existing 2014 tracer study to demonstrate the 0.5-log post-filtration disinfection, the limits of that tracer study apply. The water system must use a contact time "T" of 66 minutes, which applies as long as the reservoir level does not drop below 14.2 ft (147,100 gallons). Given the new capacity of the temporary treatment plant (140 gpm for the two 3-module WesTech filtration units (70 gpm each)), it is unlikely that the City will exceed the peak hourly demand flow set in the tracer study of 300 gpm. The city must measure chlorine, pH and temperature daily when the plant is in use from the reservoir effluent line (considered to be the "first user") for purposes of calculating CT required.

The new water treatment skid will require an operator with a Water Treatment 1 license, which is the same as the previously approved temporary membrane skid.

The plans are approved provided the following conditions are met:

- A combined filter effluent turbidimeter is supplied. Alternatively, reporting of the highest individual effluent turbidity may be allowed if the temporary nature of the new membrane system makes having a combined filter effluent turbidimeter infeasible.
- Programming is completed such that $LRV_{ambient}$ is calculated every 15 minutes with the results, formulas, and variable viewable or otherwise accessible to the operator and for regulatory inspections. $LRV_{ambient}$ uses the same equations as LRV_{DIT}, with the exception that the calculation uses the most recent direct integrity test and operating conditions (flows, TMP, water temperature) prior calculation. See the enclosed memo regarding $LRV_{ambient}$, refer to the appendices in this letter for more information.

- PLC/SCADA programming accounts for the following operation conditions that are specific to the Toray HFUG-2020AN membrane module proposed as follows:
  - Maximum flux: 120 gpd/ft^2 @ 20 degrees C
  - Maximum flow rate per module: 80.75 gpm @ 20 degrees C
  - Minimum Static DIT pressure: ~~17.44~~ 18.24 psig*
  - Maximum Trans Membrane Pressure: 29 psi @ 20 degrees C
  - Maximum allowable pressure decay rate: 0.08 psi/min
  - Minimum LRV$_{ambient}$: 4.0-log**
  - Filter unit is automatically taken off-line should individual filter effluent turbidity exceed 0.15 NTU for more than 15 consecutive minutes (the filter unit will need to undergo a direct integrity test prior to being returned to service).

***Note: The 17.44 psi minimum static DIT pressure assumed a backpressure of 2.98 psi. The backpressure for the modules in the WesTech AltaPac APIII skid is 3.65 psi, which requires a minimum static DIT pressure (i.e., ending DIT test pressure) of 18.24 psig for the DIT to be valid. Please ensure this change is made for both the existing membrane filter unit and the identical new filter unit.**

**** Refer to the enclosed LRV memo sent with this letter for more information regarding new reporting requirements for LRV$_{ambient}$.**

Until we receive verification that the conditions have been met and final approval has been issued, the facility is not approved for use. Upon completion of the project, the engineer must complete the Project Final Approval Request Form to verify in writing that construction was completed according to the submitted plans. If substantial changes are made, a set of as-built drawings must be submitted. Documentation demonstrating how the above conditions were met should reference Plan Review #111-2023 and can be emailed to me at me at evan.e.hofeld@oha.oregon.gov or mailed to:

Attn: Evan Hofeld
OHA-Oregon Drinking Water Services
PO Box 14450
Portland, OR 97293-0450

This remainder of this letter includes the following summary tables:

1) Table 1 - Log removal credits (LRC) granted for the selected membrane modules.
2) Table 2 - Operating limits that help ensure that the log removal credits granted are met.
3) Appendix A - Explanation of operating limits and terms in Table 2.

4) 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.
5) Appendix C – Product specifications for the selected membrane modules.

Thank you for your cooperation and if you have any questions, please feel free to contact me at (971) 200-0288 or e-mail me at evan.e.hofeld@oha.oregon.gov.

Sincerely,

Evan Hofeld, PE
Regional Engineer
Drinking Water Services

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Each membrane filter unit 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 for the installed 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 (300 Seconds)
DIT starting test pressure	20 psi (or per manufacturer's recommendation)
Minimum allowed DIT pressure	18.24 psi throughout the 5-minute DIT duration
Maximum allowable pressure decay rate (PDR) upper control limit (UCL)	UCL = 0.08 $^{psi}/_{min}$ (calculated using a max flow of 70 gpm/filter unit w/3 HFUG-2020AN modules/filter unit)
Minimum DIT pressure transducer accuracy (and span in psi) for the established UCL[1] [psi/min]	$\pm$ 0.05 % of span ($\pm$ 0.25 psi @ 50 psi) for the WIKA A10 sensor (span = 0 – 50 psi expected measurement range)
Membrane Minimum Performance ($LRV_{ambient}$)	$LRV_{ambient}$ = 4.0-log (must be $\geq$ 4.0-log LRC)
DIT Sensitivity (LRV_{DIT}) - depends on the pressure transducer accuracy in measuring a response due to a breach (e.g., broken fiber) in the membrane filtration units.	4.57-log. LRV_{DIT} is the maximum LRV that can be reliably demonstrated by the DIT given the use of the WIKA A-10 pressure sensor @ $\pm$ 0.05% of span. The challenge study demonstrated 5.17-log removal value ($LRV_{C\text{-}TEST}$)
Maximum transmembrane pressure (TMP)	29 psi at 20°C
Maximum allowed filtrate flux [gfd]	120 $^{gal/SqFt}/_{day}$ @ 20°C (80.75 gpm/module x 3 modules = 242.25 gpm/filter unit)
Individual filter effluent (IFE) turbidity	Not to exceed 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 (i.e., shut filter unit 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 typically 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 LRC for *Cryptosporidium* shown in Table 1. $LRV_{ambient}$ values displayed in SCADA should be calculated using the formulae, constants, and variables shown in Table B-1 of Appendix B.

Please ensure the following programming is maintained to ensure compliance:

1. Direct integrity testing parameters programmed into the PLC/SCADA system must include the following:
   a. A **direct integrity test pressure**, which is to be set no less than 18.24 psi.
   b. An **upper control limit (UCL)**, which is set no less than 0.08 psi/min as a pressure decay rate that indicates a failure of the direct integrity test and prompts an automatic shut-down of the filtration unit.
   c. A **log removal value ($LRV_{ambient}$)** reflective of particle and pathogen removal in the 3 micron (μm) or less size range that is calculated every 15 minutes based on current ambient operating conditions (a metric commonly referred to as $LRV_{ambient}$) and the most recent direct integrity test result. In summary, **$LRV_{ambient}$** is the performance indicator used to demonstrate the minimum 4.0-log (99.99%) *Cryptosporidium* removal that the membrane filters have been credited with.

2. Alarm set points should ensure the following operating limits are not exceeded and if they are exceeded, prompt an automatic shut-down of the filter unit:
   a. Maximum flux of 120 gfd (242 gpm/filter unit), or equivalent flow setpoint.
   b. Maximum transmembrane pressure (TMP) of 29.0 psi.
   c. Minimum $LRV_{ambient}$ of 4.0-log (calculated every 15 minutes and visible in SCADA)
   d. Maximum direct integrity test pressure decay rate (UCL) of 0.08 psi/minute.
   e. An alarm set point established to trigger a membrane unit shut down when the combined filter effluent turbidity exceeds 0.15 NTU for more than 15 minutes so that a direct integrity test can be performed on the affected unit.

3. SCADA programming should ensure that the variables, constants, and equations used to determine the pressure decay rate and $LRV_{ambient}$ are viewable to the operator for verification purposes.

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:

1) Continuously using a turbidimeter that monitors the effluent turbidity from each membrane unit, often called **individual filter effluent (IFE)** turbidity monitoring, and

2) 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, constatns 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 = 30.11 gallons (113.98 liters = 0.114 m^3) for 3 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] = 3.65 psi = 101.13 inches of water.
P_{Test} used for ΔP_{eff} equation [psi]	Constant[4] = 20 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

[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 _____psi
[4] PLC programming is using the UCL of _____psi for P_{test} in the ΔP_{eff} equation, which will yield a lower and more conservative ALCR

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 Detroit's two temporary WesTech UF AltaPac membrane filter units containing 3 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]	$\frac{527 \bullet \Delta P_{tf} \bullet (175 - 2.71 \bullet T + 0.0137 \bullet T^2)}{TMP \bullet (460+T)}$	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]	$\frac{527 \bullet \Delta P_{tf} \bullet (175 - 2.71 \bullet T + 0.0137 \bullet T^2)}{TMP \bullet (460+T)}$	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} = 18.24 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} = 3.65 psi (101.13 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)

Upper Control Limit (UCL) in psi/minute

UCL = 0.08 psi/min is the maximum allowable pressure decay rate for the direct integrity test as calculated using MFGM equation 4.17 where,

Q_p = 70 gpm
P_{atm} = 13.9 psi
LRC = 4.0 log
V_{sys} = 30.11 gallons (113.98-L = 0.114 m^3)
VCF = 1

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

ALCR = 23.91 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} = 18.24 psi
T = 41 °F
TMP = 29.04 psi
BP = 3.65 psi (BP_{max})
P_{atm} = 13.9 psi
$(P_{test}) - BP) / (P_{test} + P_{atm})$ = 0.4303 (0.483 using P_{test} of 20 psi)
Y ≃ 0.77 (0.74 using P_{test} of 20 psi)

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.

d_{fiber}	0.7 mm	Hollow-fiber lumen diameter
L	95 mm	Depth of membrane into potting material
f	0.027	Friction factor (from iterative method)
Re	20,000	

K = f x (L/ d_{fiber}) = **3.66**
(Equation C.6 EPA Manual)

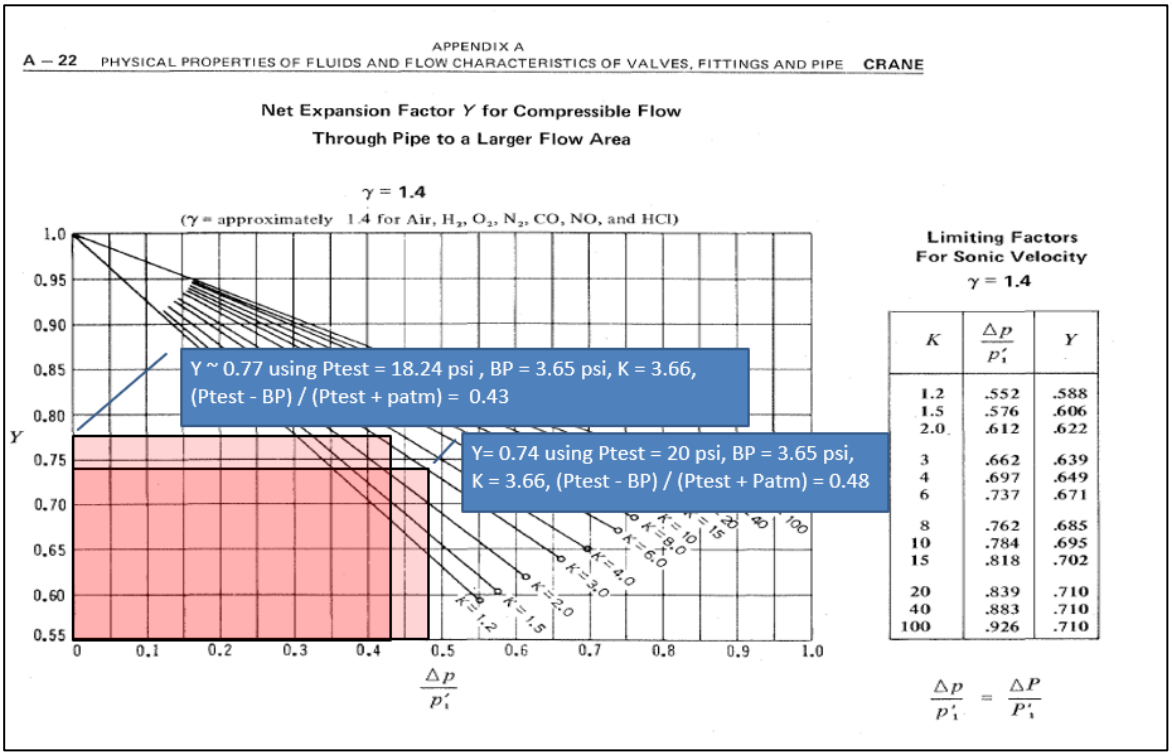
Note: this value is fixed for all HFS membrane systems

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

(Equation C.5 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



APPENDIX A
A – 22 PHYSICAL PROPERTIES OF FLUIDS AND FLOW CHARACTERISTICS OF VALVES, FITTINGS AND PIPE CRANE

Net Expansion Factor *Y* for Compressible Flow Through Pipe to a Larger Flow Area

$\gamma = 1.4$
(γ = approximately 1.4 for Air, H_2, O_2, N_2, CO, NO, and HCl)

Y ~ 0.77 using Ptest = 18.24 psi , BP = 3.65 psi, K = 3.66, (Ptest - BP) / (Ptest + patm) = 0.43

Y= 0.74 using Ptest = 20 psi, BP = 3.65 psi, K = 3.66, (Ptest - BP) / (Ptest + Patm) = 0.48

Limiting Factors For Sonic Velocity
$\gamma = 1.4$

K	$\frac{\Delta p}{p_1'}$	Y
1.2	.552	.588
1.5	.576	.606
2.0	.612	.622
3	.662	.639
4	.697	.649
6	.737	.671
8	.762	.685
10	.784	.695
15	.818	.702
20	.839	.710
40	.883	.710
100	.926	.710

$\frac{\Delta p}{p_1'} = \frac{\Delta P}{P_1'}$

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} = 4.57-log (> LRC) which is the sensitivity of the DIT using MFGM equation 4.9 where,

Q_p = 70 gpm (maximum design feed flow through a filter unit)
ALCR = 23.91 (calculations shown above)
P_{atm} = 13.9 psi
V_{sys} = 30.11 gallons (113.98-L = 0.114 m^3)
VCF = 1

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

ΔP_{test} = 0.021 psi/min (< 0.08 psi/min UCL) is the sensitivity of the Wika A-10 transmitter.

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 4.189-log, which is still greater than the 4.0-log removal credit.**

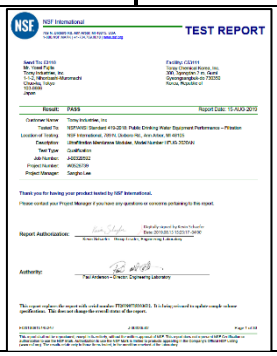
Appendix C

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)	696 ft^2 (64.66 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.


TEST REPORT