Implementation Manual

for the use of

Hollow Fiber, Micro Filtration and Ultra Filtration Membrane Filtration Technology

to satisfy

Pathogen and Turbidity Removal Requirements

under the

Safe Drinking Water Act

**North Dakota Department of Health
Environmental Health Section
Division of Municipal Facilities
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1.   Purpose

The purpose of this document is to provide guidance for the use of membrane filtration technology for pathogen and turbidity removal in the state of North Dakota. Such guidance is given in the context of the following:

- Membrane filtration for pathogen removal is still in developing stages in the United States. Adequately documented, full-scale experience is not wide spread.
- The United States Environmental Protection Agency (EPA) is developing regulations containing design and implementation conditions for the degree of credit awarded for removal of *Cryptosporidium.*
- EPA has finalized the *Membrane Filtration Guidance Manual* (EPA 815-R-06-009 Nov 2005). This document provides information and procedures for meeting the criteria set forth in EPA's manual. Please keep in mind that any guidance may need to be reviewed and adjusted relative to future regulations.

2.   Membrane Filtration Definition

Membrane filtration is defined as a pressure-driven separation process in which particulate matter larger than 1 micrometer (µm) is rejected by a non-fibrous, engineered barrier primarily through a size exclusion mechanism and which has a measurable efficiency of a target organism that can be verified through the application of a direct integrity test (DTI). This document addresses the common membrane technology classifications of microfiltration (MF) and ultrafiltration (UF) using hollow fibers. Other membrane configurations (such as spiral wound membranes), or membranes applied for purposes other than turbidity and suspended pathogen removal (such as removal of dissolved solids), are not addressed.

For consistency, two definitions are provided:

- Module means the smallest component of a membrane unit in which a specific membrane surface area is housed in a device with a filtrate outlet.
- Unit means a group of membrane modules that share common valving which allows the unit to be isolated from the rest of the system for the purpose of integrity testing or maintenance.

EPA's *Membrane Filtration Guidance Manual* should be consulted for additional definitions.

3.   *Giardia* Cyst and *Cryptosporidium* Oocyst Removal Credit

The maximum *Giardia* cyst and *Cryptosporidium* oocyst removal credit will be evaluated on a case-by-case basis.

4.   Virus Removal Credit and Reduction Requirements

Virus removal credit by membrane filtration will be evaluated on a case-by-case basis.

Virus reduction post-membrane filtration is required so that virus inactivation and other microbial minimum treatment requirements are achieved. A 4.0-log reduction of viruses by removal/inactivation treatment is required.

5. Overview of the Various Membrane Filtration Processes

The EPA *Membrane Filtration Guidance Manual* contains an overview of the various membrane filtration processes, including descriptions of the various classes, membrane material, geometry, module construction, driving forces, basic principals of design and operation, and hydraulic configurations. Emphasis is given to the manner in which each of these characteristics relates to the membrane filtration process applied for pathogen removal.

6. Hydraulic Modes of Operation

An overview of hydraulic modes of operation follows:

- Hollow fiber flow path can be either inside-out or outside-in.
- Hydraulic configuration is either deposition mode or suspended mode.
- In a deposition mode hydraulic configuration, the concentration of suspended material on the feed side of the membrane is assumed to be equivalent to the concentration of suspended material in the feed stream, independent of time or position in the membrane system, as the suspended contaminants are removed from the process stream and deposited in the accumulated cake layer. Therefore, all systems operating in deposition mode have a Volumetric Concentration Factor (VCF) equal to one.
- In any suspension mode variation, the ratio of the concentration of particles in suspension on the feed side of the membrane to the concentration of the particles in the influent feed must be less than or equal to a VCF of 4.
- The deposition mode may include a periodic back pulse with air, filtrate, and/or oxidants to dislodge particles trapped on the membrane surface.
- Cross flow is a type of suspension mode operation. Air and/or water are continuously or intermittently applied as a scouring force to keep particles suspended or to re-suspend deposited particles. Where a portion of the reject is recycled to the suction side of the pump, the mode is called small volume crossflow. To prevent excessive concentration of particles on the feed side of the membrane, recycle must be limited to 10% of the feedflow. Accumulated solids must be removed from the system during the backwash cycle. The VCF must not exceed 4 over the course of any filtration cycle.
- Feed-and-bleed is a type of suspension mode operation similar to crossflow in that particles are held in suspension on the feed side of the membrane while a continuous concentrate waste stream removes particles from the stream. As a result, the VCF must be 4 at the end of the filtration cycle.

7. Implementation Considerations

The EPA *Membrane Filtration Guidance Manual* (Section 7.0) should be consulted for system design and operation of membrane unit processes including pretreatment, backwashing, chemical cleaning, integrity testing, and post-treatment. Additionally this section discusses some of the most significant design issues associated with flux, water quality, temperature compensation, cross section control, and reliability. Residuals and concentrate disposal are also discussed.

Construction sequence, customer service, and waste dispersal must be addressed. Waste dispersal includes wastes generated from removal of the membrane preservation solution, flushing the system prior to membrane installation, initial system disinfection, and performance verification period operation.

Membrane filtration units may be fitted with block-and-bleed valve arrangements or removable spools to eliminate the potential for backflow. See section 7.0 of EPA's Guidance Manual for additional information.

All membrane materials and associated piping, etc. must be ANSI/NSF Standard 61 certified. Chemicals used in any membrane unit cleaning process must be ANSI/NSF Standard 60 certified.

8.   Product Specific Challenge Test

Removal efficiency of microbial pathogens of concern must be established through a product specific challenge test. Specific and detailed challenge test criteria must be followed. Challenge testing demonstrates the removal efficiency a membrane module is capable of achieving.

The EPA *Membrane Filtration Guidance Manual* provides specific procedures for meeting the challenge test criteria. Such procedures must be followed to satisfy the following challenge test requirements:

- Full-scale vs. small-scale module testing.
- Appropriate challenge particles.
- Challenge particulate concentrations.
- Test operating conditions.
  - Maximum recovery
  - Representative VCF
  - Maximum flux
- Calculation of removal efficiency.
- Establishment of a quality control release value (QCRV) for a non-destructive performance test (NDPT).

Challenge testing must be conducted using *Cryptosporidium* oocysts or a surrogate that has been determined to be removed no more efficiently than *Cryptosporidium* oocysts. Indirect water quality measurements such as turbidity, particle counting, or conductivity must not be used to determine removal efficiency of pathogens. The concentration of the organism or surrogate used during challenge testing must be determined using a method capable of discretely quantifying the specific challenge particulate used in the test.

The challenge test protocol and results must demonstrate the removal efficiency. Previously conducted challenge testing demonstrating acceptable removal and not significantly deviating from EPA's *Membrane Filtration Guidance Manual* challenge test criteria will be considered. The challenge test protocol and results used to demonstrate removal efficiency acceptance must be submitted to this Division.

Modified membrane modules must be retested if the modifications may affect the membrane characteristics, removal efficiency, or the NDPT results and associated QCRV. Some examples of modifications requiring retesting include but are not limited to: membrane material, membrane backing material, pore size distribution, porosity, permeability, or symmetry. Modifications to the hydraulic configuration of a filtration system will require retesting if the concentration of suspended solids on the feed side (VCF) may be higher. An example of an increased VCF is when the configuration was originally tested in the dead-end (deposition) mode and the proposed configuration is crossflow (suspension mode)

The product specific challenge test report must include the methodology used in determining the QCRV for the NDTP. The QCRV must be sufficient to justify an awarded log removal value (LRV) and 3 μm resolution.

9.   Quality Control Release Value (QCRV)

The NDPT and QCRV are necessary because the challenge test criteria do not require that every membrane module be subjected to challenge testing. A non-destructive performance test (e.g. bubble point test or pressure decay test) may be applied to each production membrane module in order to verify removal efficiency of those that did not undergo challenge testing. A QCRV must be established for the NDPT that is directly related to the minimum removal efficiency of the membrane filtration process awarded LRV as demonstrated during challenge testing. Membrane modules that do not meet the established QCRV are not eligible for the removal credit demonstrated during challenge testing.

Each module must be accompanied by documentation of the successful application of the product specific QCRV. The documentation for each module must be provided to the system owner or its representative for acceptance.

10.   Direct Integrity Test (DIT)

In order to receive *Giardia* cyst and *Cryptosporidium* oocyst removal credit, the removal efficiency of a membrane filtration process must be routinely verified during operation using DIT. The DIT must be applied to the physical elements of the entire membrane unit, including membranes, seals, potting material, associated valves and piping, and all other components which could result in contamination of the filtrate under compromised conditions.

The currently acceptable DIT is a pressure-based test based on bubble point theory, which involves applying a positive pressure to one side of a wetted membrane barrier and monitoring for pressure loss or pressure decay in order to establish whether an integrity breach is present. The DIT system must be capable of pre-programmed automatic operation or manual initiation.

The DIT applied to a membrane unit must meet performance criteria for resolution, sensitivity, and frequency as follows:

- Resolution-The DIT must be responsive to an integrity breach of 3 µm or less.
- Sensitivity-The DIT must be able to verify an awarded LRV.
- Frequency-A DIT must be conducted, as a minimum, on each membrane unit at least daily.

The DIT sensitivity is primarily a function of the smallest, reliably-measured response the equipment can detect, referred to as the threshold response. Sensitivity may also be affected by the diffusion of air through the water in the wetted pores of the membrane, referred to as threshold response.

The EPA *Membrane Filtration Guidance Manual* describes the DIT and how results are used to determine both sensitivity and the removal efficiency.

DIT Parameters are set forth below.

- Use of ASTM D 6908-03 Standard, Practice A, Pressure Decay Test for DIT procedures is required with the following stipulations:
  - time for the decay rate determination must be at least five minutes
  - the measured pressure decay rate may be corrected by subtracting the pressure decay due to diffusive air flow from the measured pressure decay
  - the more conservative approach should be taken assuming all pressure decay is related to integrity

- conservative membrane property parameters should be used when calculating the minimum required initial test pressure to meet the 3 μm resolution criteria. Intrinsic properties of manufactured membrane pores are more than likely not the same as the properties when there are defects, tears or oversized holes in the membrane material. Therefore, the conservative values of pore shape, contact angle, and surface tension must be used. Additionally, any hydrostatic backpressure must be included in calculating the minimum initial test pressure. Using the conservative values $k = 1$, $\theta = 0$, and $s = 74.9$ dynes/cm @ 5 degrees C results in initial $P_{test} = 14.5$ psi + maximum hydrostatic backpressure.

  A failed test results if the pressure at the end of the test is below the initial pressure calculated above. Initial calculated test pressure should be increased to account for some baseline decay to ensure adequate applied pressure through the duration of the test. As a result, the minimum initial test pressure must be: $P_{test} = 14.5$ psi + hydrostatic backpressure + baseline decay.

- DIT parameters must be viewable by the operator as follows:
  - Initial pressure
  - Final pressure
  - Stabilization period (if applicable)
  - Decay rate determination duration
  - LRV (optional)

- DIT operational control criteria are as follows:
  - Optimization - To achieve optimized removal of particulate pathogens, the units should be operated at or below the DIT pressure decay rate (psi/min) corresponding to a LRV that was awarded
  - Alarm - To alert the operator of potential problems, an alarm must be energized and the operator informed when the DIT pressure decay rate (psi/min) corresponding to an LRV of 0.5 log greater than the awarded LRV is reached.
  - Any membrane unit reaching the DIT pressure decay rate (psi/min) corresponding to awarded LRV may result in a regulatory action.

11. Diagnostic Testing

Diagnostic testing equipment must be provided to isolate a compromised module and/or fiber. A means to visually inspect modules while simultaneously conducting a DIT must be provided. Alternatively, sonic testing equipment yielding a relative accelerometer reading must be provided if visual inspection cannot be preformed. Sonic testing is recommended.

Single module bubble testing apparatus to facilitate testing of removed modules must be provided. Please note that some diagnostic testing procedures of modules or units after a shutdown alarm condition or other unit isolation diagnostic procedure will require filter-to-waste capability

12. Continuous Indirect Integrity Monitoring

Continuous indirect integrity monitoring equipment must be used to provide a surrogate measure of membrane unit integrity for operational control and to determine compliance with turbidity treatment technique requirements.

Continuous indirect integrity monitoring equipment is required between DIT to provide some measure of performance assessment. As a minimum, continuous indirect integrity monitoring must be by continuous turbidity monitoring of the filtrate from each membrane unit. "Continuous" means monitoring at a frequency of no less than once every 15 minutes. The minimum acceptable equipment consists of: laser nephelometers; or, particle counters in combination with tungsten-filament lamp nephelometers. Particle monitors alone do not satisy the minimum equipment requirements.

The ability to multiplex these instruments may help to minimize the associated cost of utilizing laser nephelometers. In multiplexing, multiple sensors are connected to a single laser light source, detector, and control system via fiber optics. Sensors can be attached to monitor the filtrate from each membrane unit or individual membrane modules, if desired.

Filtrate operational criteria for indirect integrity monitoring are as follows:

- Optimization - To achieve optimized removal of particulate pathogens, the units must be operated at or below a filtrate turbidity of 0.1 NTU.
- Alarm - To alert the operator of potential problems, an alarm must be energized and the operator informed when the filtrate turbidity of any unit exceeds 0.1 NTU.
- DIT triggered - Whenever two consecutive, 15 minute turbidity readings exceed 0.15 NTU for any one unit, DIT must be automatically initiated on that unit.
- Shut down - Any membrane unit producing a filtrate turbidity of 0.3 NTU or greater (independent of any direct monitoring data) must be taken off line immediately for necessary diagnostic work and repair.

Turbidity treatment technique compliance is based on a filtered water turbidity of less than or equal to 0.3 NTU in at least 95% of the measurements taken each month. Samples must be representative of the system's filtered water, and at no time exceed 1 NTU. Filtered water exceeding 1 NTU in conjunction with other factors may warrant the issuance of a boil water notice.

13. Instrumentation

a. Continuous Reading and Recording must be provided and include:

- Source water turbidity recording by tungsten-filament lamp nephelometers.
- Feed water turbidity monitoring by tungsten-filament lamp nephelometers (between prefiltration and each membrane unit) is recommended.
- Pressure drop across raw water prefiltration or prefiltration on the membrane unit, as appropriate (read only).
- Pressure drop across the membrane modules (i.e. transmembrane pressure).
- Filtrate turbidity monitoring of each unit by conventional turbidity meters. Laser nephelometers or particle counters may also be used in conjunction with standard turbidity meters.
- Date, time, and results of the DIT on each unit.

Continuous reading and recording instrumentation system must be provided at the waterworks entry point to the distribution system for disinfectant residual (a residual of at least 0.2mg/L must be maintained). Turbidity monitoring of the plant effluent (requirement under the Surface Water Treatment Rule) can be accomplished by conventional turbidity monitoring or by grab sampling every four hours that the plant is in operation. Or, the combined measurements from the filtrate of each membrane unit can be averaged every four hours to also satisfy this requirement (see Appendix A of the EPA *Membrane Filtration Guidance Manual*).

Continuous reading instrumentation means an electronic sensor continuously reads the parameter and the parameter is displayed in real time. Continuous recording means one data point is stored in memory or printed at least every 15 minutes. The one data point that is stored or printed is a snapshot of the parameter at that time; it is not an average of previous data points. Equipment capable of producing a hard copy (or equivalent electronic file) showing daily trends including maximum, minimum, and average values must be provided. Electronic files must be backed up to removable media on a daily basis.

Continuous reading instrumentation requires a continuous flow through the instrument sensor. During periods of shut down, backwashing, chemical cleaning, or other maintenance activities, the flow through the sensor may stop and the instrument sensor go dry resulting in erroneous readings. These erroneous readings may create an alarm condition and shutdown the unit or prevent its restarting. Provisions should be included to prevent sensors from going dry.

b.   Air Entrainment Error

Air entrainment error caused by air bubbles being introduced into the system either during production, backwashing, chemical cleaning, or integrity testing may be falsely detected as particulate matter, artificially increasing the instrument reading. Consequently, after a backwash cycle or chemical cleaning (particularly if air is utilized in the process), instrument measurements may not be representative of filtrate quality until any entrained air is purged from the system. This purge time will vary between different membrane filtration systems and their respective backwash or chemical cleaning practices. Bubble traps may be employed to minimize or eliminate this error.

If removal of entrained air error is unsuccessful, the Programable Logic Controller (PLC) may be programmed to verify an alarm or shutdown operational control conditions immediately following an operation resulting in air entrainment so that a DIT is not triggered. Significant and continuous air entrainment problems must be addressed on a case-by-case basis.

c.   Computers and SCADA

- Automated systems used to display and record data or control functions and that are connected to computers or networks with an internet link or that use a radio system must have sophisticated encryption to prevent hacking.
- A back-up power supply must be provided to allow orderly shutdown of the computer and prevent corruption of data. The protection must cover every connection to all outside service providers such as power, cable, telephone, DSL, ISDN, etc.
- Adequate hardware must be in place to allow a high degree of SCADA and computer reliability and data security. Acceptable methods of meeting this requirement include:
  - Providing side-by-side PCs capable of performing the same tasks, with the ability to rotate the operation and monitoring tasks between the two PCs, and with those PCs having mirrored hard drives in a single PC.
  - Installing duplicate mirrored hard drives in a single PC.

- Adequate hardware and facilities must be provided for data archiving. Providing the means to back up data stored on hard disk drives to removable media on a daily basis and to maintain a back up copy of archived data at a secure off-site location would meet this requirement.
- SCADA and computer systems must have adequate protection from voltage surges and spikes on the power supply and external data links.

- Except for local displays and sensors designed for the environment, all electronic elements must be located in an area free of excessive moisture, corrosive chemicals or excessive heat or be protected by an appropriately rated NEMA enclosure.

- SCADA and computer systems used to meet the continuous recording requirements must record an observation on a minimum frequency of once every 15 minutes, unless a greater recording frequency is required.
- SCADA and computer systems used to meet the monitoring and recording requirements must provide dedicated and continuous displays that show a minimum 24-hour trend of results for each parameter. The display panel(s) must be located in an area where it can be routinely viewed by the operators. Sufficient display panels and software should be provided to allow the data to be observed without changing screens. However, if changing screens is necessary, then the displays of the required data must be easily accessible without excessive scrolling through multiple screens.
- In the event of a computer malfunction, all mandatory continuous in-line analyzers must feature a display of the test results that is independent of any central computerized data system. Providing a separate display at each in-line unit would meet this requirement.
- Manual Operation: System pumps, chemical feeders and other essential electrical equipment controlled through SCADA or an automated control system must have the capability for independent manual operation through a HOA switch.

d.   Laboratory Instrumentation

Laboratory type, bench instrumentation units must be provided to perform daily grab samples, comparisons to the continuous instrumentation, and provide for substitution of continuous reading when equipment is out of service. Bench units must measure turbidity, disinfectant residual, temperature, and pH.

e.   Flow Rate Measurement
        Flow measuring equipment must be provided to measure:

- Source water (gpm and totalized).
- Filtrate from each unit (gpm and totalized).
- Recycle to each unit (% of feed flow, if applicable).
- Entry point to the distribution system (gpm and totalized); and,
- Waste flow (gpm and totalized).

f.   Alarms and Automatic Shutdown

An alarm system must be provided which will report alarm conditions and shut down the treatment plant and entry point flow. All alarm conditions must be reported to a location manned 24 hours per day or activate an auto-dialer. The following alarm and shut down set point conditions must be provided on a case-by-case basis:

- Source water turbidity.
- Feed water turbidity (where appropriate).
- Low feed water flow.
- Filtrate turbidity on each unit exceeding operational criteria.
- Membrane DIT exceeding operational control criteria.
- Excessive transmembrane pressure at each unit.
- Entry point disinfectant residual (high and low).
- Low air pressure.

g.   Sample Taps

Sample taps must be provided to monitor the following:

- Source water.
- Source water storage tank effluent.
- Feed water after prefiltration.
- Filtrate from each membrane unit.
- Combined filtrate from all units.
- The presence of cleaning solutions used in either backwash or cleaning operations.

14. **Reliability**

The need for treatment units on line, units in standby, duplication of units, and components or spare parts on hand or readily available will be decided on a case-by-case basis.

The number of membrane units will be a function of the overall system design, and storage capacity, and design maximum daily demand.

Redundancy of pumps, motors, chemical feeders, SCADA system, etc. must be in accordance with Recommended Standards for Waterworks (i.e. Ten State Standards).

The treatment plant's electrical system and essential electronic components should be closely evaluated for reliability. The environment the electrical system and essential electrical components is subjected to must be addressed by use of appropriate enclosures and environmental control. The need for additional filtering, voltage regulation, surge protection, interference protection, etc. must be addressed.

Appurtenances should be provided and pumping rates should be controllable to facilitate operation with a few modules removed, or a membrane unit out of service. Appurtenances would be necessary to cap-off the module location or isolate the membrane housing from the unit when one or more modules are removed or not in use.

Special consideration must be given in the design of the building for equipment accessibility, piping locations, and noise abatement.

15. **Operation and Maintenance Manual (O&M)**

The specifications must include a requirement that a detailed, site specific, O & M Manual be provided by the engineer directly to the system's owner. The designated operator in charge should have sufficient time to review the O & M Manual prior to the manufacturer's onsite training and thirty-day start-up period.

16. **Reporting and Recordkeeping**

a.   Monthly Operations Report (MOR)

A MOR must be submitted to the Division within 10 days of the end of each month of operation.   An example MOR is included in Appendix A. Appendix A also includes instructions for each item on the recording form. The form and instructions are self-explanatory.

Summary reports must be submitted with the MOR and summarized, as appropriate:

- All alarm and shutdown conditions.
- All diagnostic testing and subsequent repair steps taken and follow-up DIT results.
- Any DITs which were triggered by indirect integrity testing.

Additionally, those applicable report forms associated with the various surface water treatment rules shall be submitted with the MOR.

b.   Membrane Module Records

Detailed records for each membrane module should be kept according to each module serial number. Records should include dates, location, factory test data, repairs, replacements, etc. for each module.