Drinking Water Operator Certification Training

Module 19:
Membrane Filtration

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Appendix

Unit 1 – Overview of Membrane Filtration

Unit 1 - Learning Objectives

As a result of this unit, the learner will:

- Receive a comparison of the removal mechanisms of membrane filtration to conventional granular media filtration and bag and cartridge filters.
- Review the current uses of membrane filtration in water treatment.
- Be given a comparison of the four levels of membrane filtration in terms of pore size, pressure drop, and particle size removal.

Membrane filtration is a rapidly expanding field in water treatment. There are many different types of filters available in a wide range of pore sizes and configurations. In addition, there are numerous possible applications for membrane filtration ranging from the removal of relatively large particulate material to the removal of dissolved compounds.

Definition

A **membrane** is a semi-permeable thin layer of material capable of separating contaminants as a function of their physical/chemical characteristics.

- A more common way to express this is: A membrane is a thin layer of material that will only allow certain compounds to pass through it. Which material will pass through the membrane is determined by the size and the chemical characteristics of the membrane and the material being filtered.

Comparison to Conventional Treatment

Conventional Filtration Design

- Conventional filtration relies on a number of mechanisms to remove particulate and dissolved material from the filter influent; these mechanisms are adsorption, settling, and straining.
  - These mechanisms are illustrated in the following graphic.

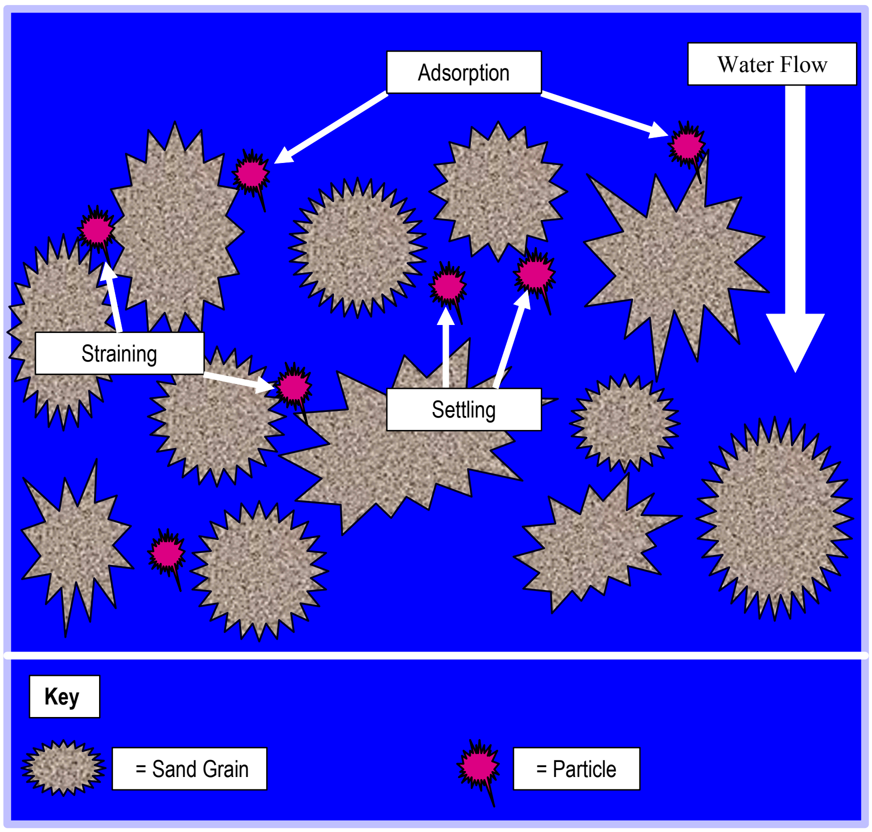


Figure 1.1 Conventional Filtration Removal Mechanisms

- Although conventional filtration typically produces a high quality of finished water, the probability of capture is something less than 100%.
  - Regardless of how well the filter is performing, some particulate material will not be captured in the filter.

Membrane Filtration Design

- Membrane filtration is a mechanical barrier that uses a straining mechanism only to remove material from the water.
  - If the barrier is intact, no particles larger than the membranes pore size can pass through the filter.
  - This is illustrated in Figure 1.2.

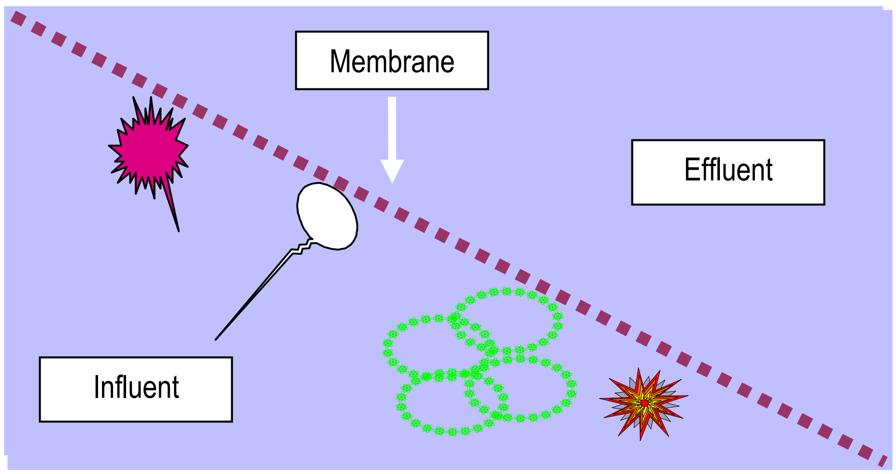


Figure 1.2 Membrane Filtration Mechanism

  - The process of particulate removal n the microfiltration membrane process is through size exclusion. An exception to this is found in larger molecular substances such as humic and fulvic acids. Adsorptive affinity to the membrane can influence removal of these larger molecules.

Comparison to Bag or Cartridge Filtration

Both membrane filtration and bag or cartridge filtration utilize mechanical filtration. There are significant differences in the technologies:

- Membrane filtration systems utilize automatic cleaning procedures to maintain filter life.
  - A membrane system can be backwashed and undergo other cleaning procedures to maintain filter flow and preserve the life of the filter.
  - Bag or cartridge filters are discarded after the filter becomes clogged with particulate material.
- Membrane filtration systems offer a variety of levels and much finer levels of filtration.
  - Although bag and cartridge filters can be purchased in many pore sizes, the pore sizes tend to be much larger than those that can be supplied by a membrane filtration system.

History of Membrane Treatment

1920s	Membrane filters were first used in the 1920s in a laboratory setting to perform separations.
1959	Reverse osmosis (RO), a type of membrane filtration, was first demonstrated at the University of Florida.
1967	The first major RO facility was constructed in Plains, Texas.
1970s	Membrane filtration facilities numbered fewer than ten in the world.
1980s	World-wide membrane filtration facilities increased to approximately 100.
1990s	World-wide membrane filtration facilities continued to grow, and neared 1000.
2003	There are approximately 10,000 membrane filtration facilities operating worldwide.

Membrane Filtration Uses in Water Treatment.

- Desalination of salt water to produce potable water remains the primary use of membrane filtration.
  - Although this is an expensive process, it is practiced in areas with limited sources of fresh water.
- Filtration of surface or ground water under the direct influence of surface water (GUDI) can be accomplished using membranes with the largest pore sizes.
  - Tighter membranes (those with smaller pore sizes) are used for other applications such as softening or the removal of dissolved contaminants.
- The process is used as a pretreatment step in water treatment.
  - “Loose” membranes, those with larger pore sizes, are often used to pretreat water prior to filtering with a tighter membrane.

Regulatory Perspective

The primary use of membranes from a regulatory perspective is in compliance with the Surface Water Treatment Rule (SWTR) and its children, the Enhanced SWTR, the Long Term 1 and Long Term 2 SWTRs.

- Even the loosest membranes can be used for this application.
- Membranes from many manufacturers and of many pore sizes have been shown to provide more than sufficient log removals of *Giardia* cysts and *Cryptosporidium* oocysts, as well as producing water that easily complies with effluent turbidity requirements of the SWTRs.
- In addition to SWTR compliance, tighter membrane filters can be used to remove dissolved substances from the water. For instance, membranes have been used to remove herbicides and/or pesticides from source waters in many locations.

System Configurations

There are two basic configurations that could be used for a membrane filtration system:

- The filtration is used as the only treatment process.
    - Typically, fairly high-quality source water is required for the membrane to be used as the only treatment process.
- The filtration is used in conjunction with other treatment processes.
    - The membrane is typically used as the final filtration step to polish the finished water, although a looser membrane could be used as a pretreatment step prior to filtration through a tighter membrane.

Before filtration system, the intake structures should included screening devices to prevent or minimize large objects/debris from entering with the raw water.

Principles of Membrane Filtration

Membrane filtration is a mechanical filtration technique which comes as close to offering an absolute barrier to the passage of particulate material as any technology currently available in water treatment.

In order to understand the concept of membrane treatment, the concept of osmosis must be discussed.

Osmosis is a naturally occurring phenomenon that describes the tendency of clean water to dilute dirty water when they are placed across a permeable membrane from each other.

- Eventually, the concentration of the constituents in the water on the “dirty” side of the membrane will equal the concentration of the constituents on the clean side of the membrane.
- Figure 1.3 illustrates this concept.

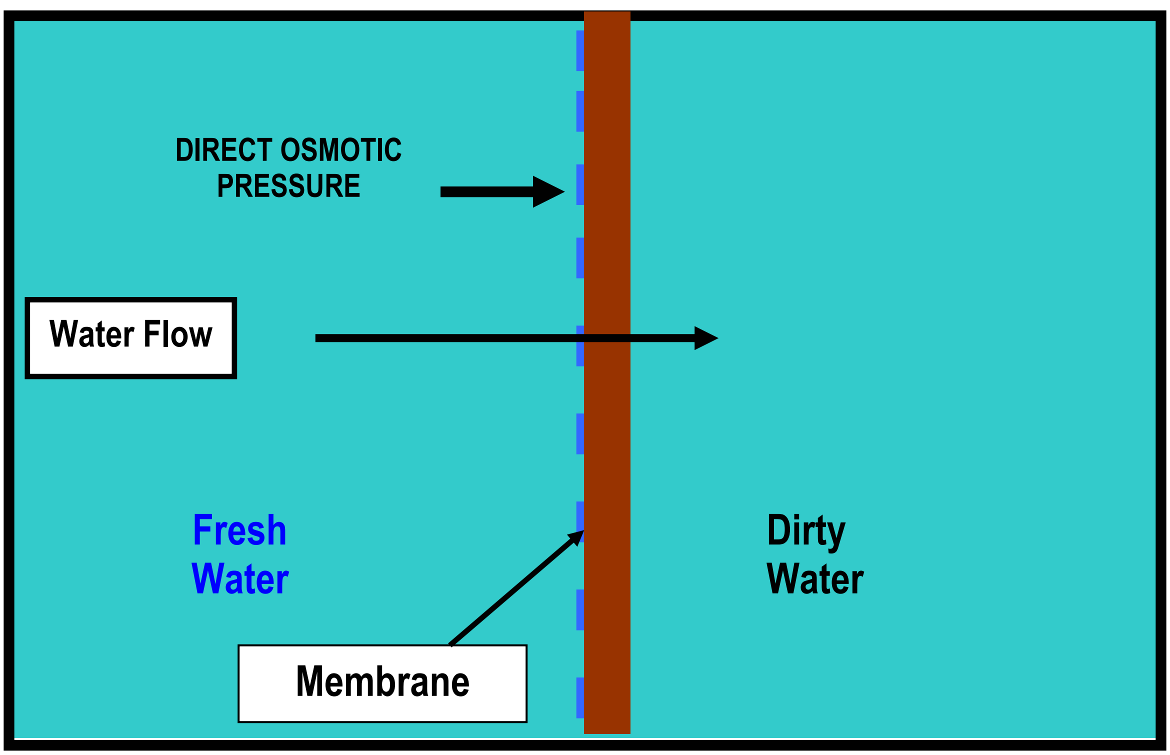


Figure 1.3 The Principle of Osmosis

Osmotic pressure is the pressure created by the difference in concentration of the constituents on either side of the membrane, and this pressure drives the osmosis process.

- Osmotic pressure drives the flow of fresh water to the dirty side.
- As the concentration of the constituents on each side of the membrane reach equilibrium (where the concentration is the same on both sides of the membrane), the osmotic pressure becomes zero and the flow stops.
- Figure 1.4 illustrates this concept.

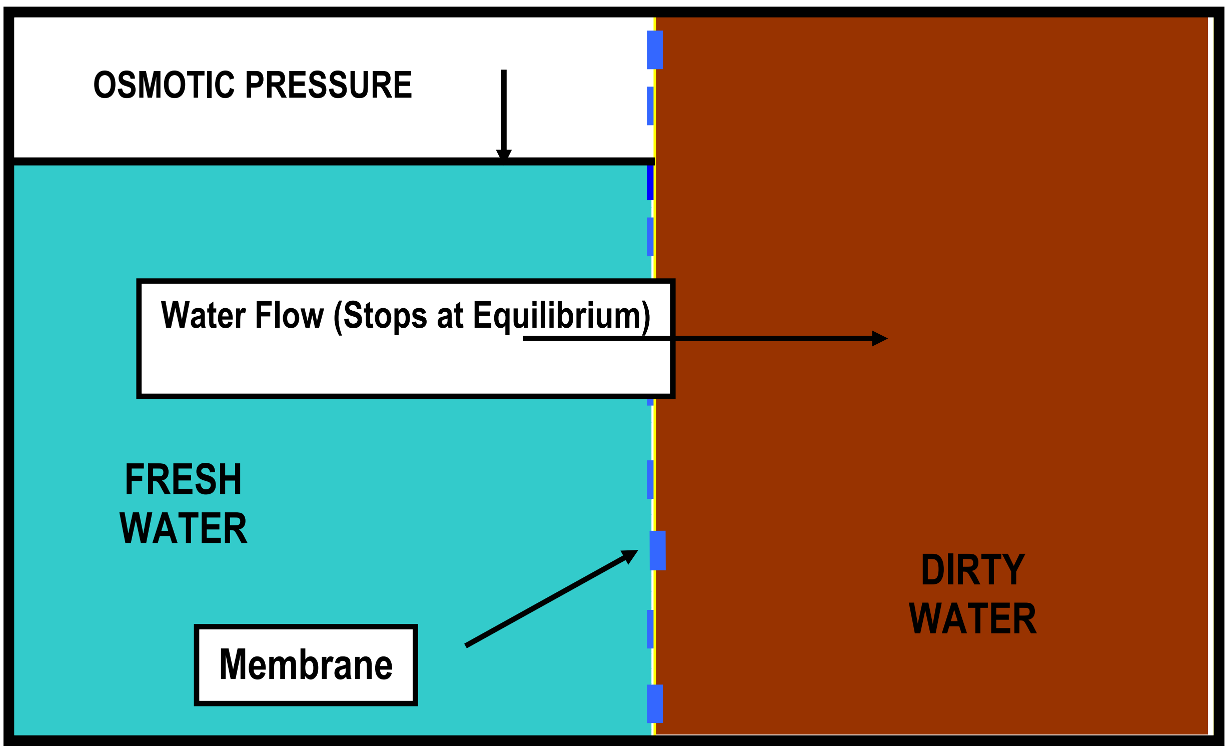


Figure 1.4 Osmotic Pressure

Osmosis is not desirable from a water treatment standpoint since the goal of treatment is to produce fresh water and not to dilute dirty water with fresh water.

Reverse osmosis (RO) is the process of forcing water from the dirty side through the membrane into the clean water side, while leaving the undesirable constituents behind on the membrane itself.

- By operating the system opposite of its "normal" direction, fresh water can be produced from raw water.
  - Undesirable constituents will be deposited on the membrane's surface and will eventually clog it.
  - If a membrane system is to be useful, there must be a way to remove this material from the membrane itself as well as from the entire system.

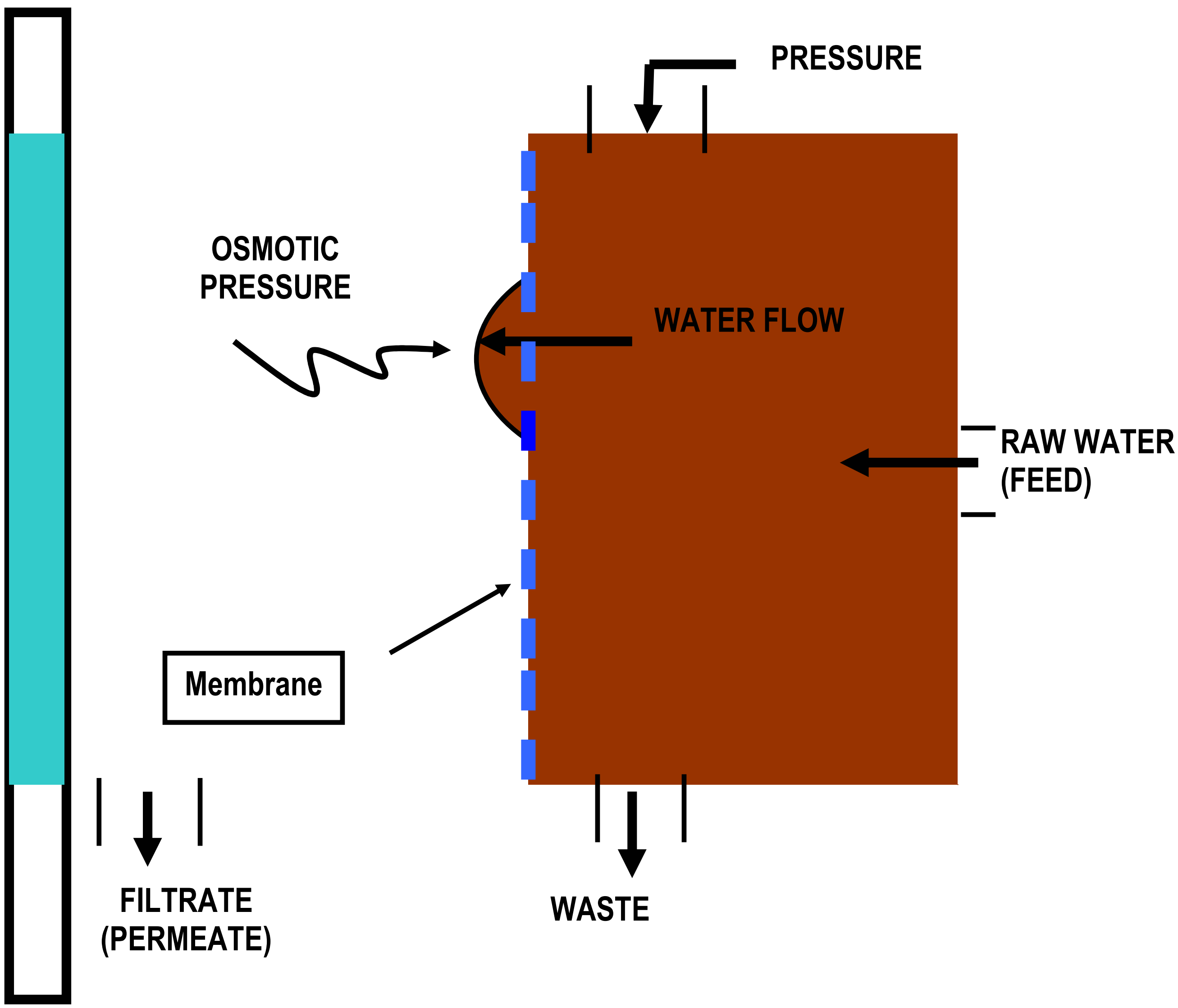


Figure 1.5 Reverse Osmosis

Considerations for RO

- Determine what constituents need to be removed from the water.
  - The smaller the molecule to be removed the tighter the membrane needs to be.
- Supply pressure to the dirty side of the membrane.
  - This extra pressure is needed to overcome the osmotic pressure of the system.
  - A pump usually supplies the pressure.
    - A pump can also help overcome headloss, which is created as constituents build up on the surface of the membrane.

Headloss is pressure drop. It is the difference between the pressure on the upstream side of the filter and the pressure on the downstream side of the filter.

Membrane Filter Applications

Membranes can be used for many different types of filtration applications; most of them are not related to potable water production. For example, they are used in industry to produce high purity process water or to remove contaminants from waste streams prior to discharge. In addition, membranes have applications in wastewater treatment.

Membranes are used to remove undesirable constituents from the water. If these constituents are dissolved in the water, very tight membranes are required; if the constituents are particulate, then a looser membrane is appropriate.

- Membrane filters are used to remove microbiological contaminants.
  - Even the loosest membrane will remove Giardia cysts and Cryptosporidium oocysts, but if virus removal is desired in addition to the removal of Giardia and Cryptosporidium, a slightly tighter membrane would be used.
- Membrane filters are used to remove both dissolved and particulate inorganic substances.
  - The nature of the substance will determine the level of tightness that is required to remove it.
- Membrane filters are used to remove organic compounds.
  - The nature of the compound will determine whether it can be removed by a particular level of membrane filtration.
  - Surface waters are generally more difficult to treat than highly organic groundwater using membrane filtration due to the increase fouling potential of surface water.

Membrane Filtration Summary

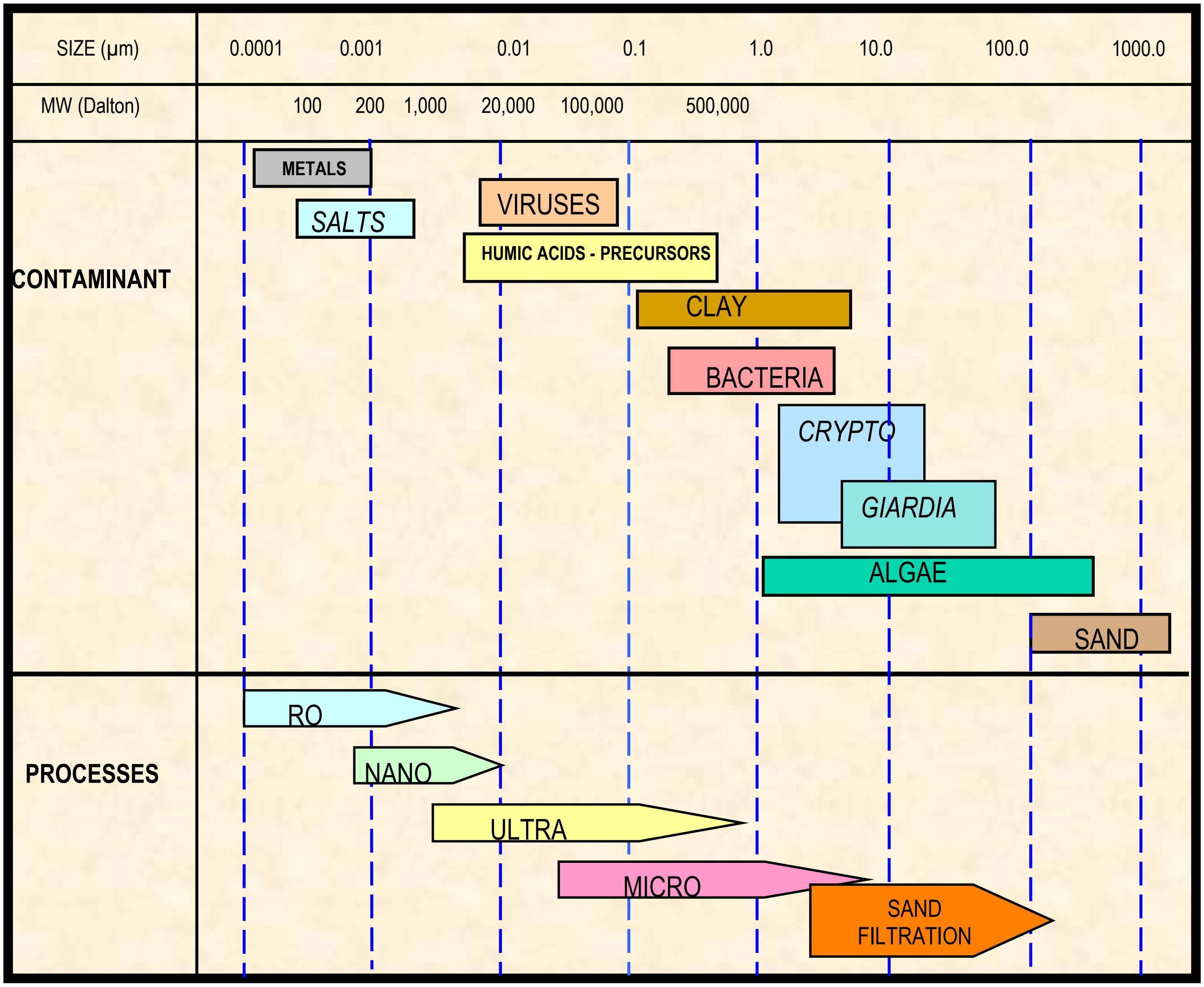
There are four levels of membrane filtration. These levels are (from largest to smallest pore size): microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. Each level has a pore size range associated with it and is used to remove certain sized contaminants.

Table 1.1

Comparison of Membrane Filtration Levels				
Filtration Level	**Microfiltration**	**Ultrafiltration**	**Nanofiltration**	**Reverse Osmosis**
Pore Size Range	0.05 – 1.0 µm	0.005 – 0.5 µm	0.0005 – 0.01 µm	0.0001 – 0.001 µm
Target Contaminants	Particulate material like algae, *Giardia*, *Crypto*, bacteria, and clays	All substances removed by microfilters plus humic acids and some viruses	All substances removed by microfilters and ultrafilters plus dissolved metals and salts	All substances removed by microfilters, ultrafilters, nanofilters plus smaller dissolved metals and salts

µm is a micron, which is one millionth of a meter, and is also known as a micrometer.

Figure 1.6 below displays possible contaminants and possible filtration processes linearly aligned with the corresponding µm and Molecular Weight Cut-Off (MWCO), which is expressed in Daltons. This figure illustrates which process (or processes) could be used for separate a particular contaminant.



Graphic courtesy of Watek Engineering

Figure 1.6 Separation Chart

The nanofiltration typically has the highest operating pressures of the other membrane processes shown.

Considerations for Selecting the Right Membrane Filter

Note the economics factors can and specific needs are the two major considerations for selecting the filter.

The fact that a reverse osmosis filter will remove all of the target contaminants begs the question of why a larger pore size filter would be used. The answer is simple economics.

- Although a reverse osmosis filtration system will remove many substances from the water, they are much more expensive to build and to operate compared to a microfiltration facility. Since a microfilter has much larger pores, the system can operate at much higher flow rates and at much lower feed pressures. More flow and less feed pressure mean smaller facilities that use less energy to produce each gallon of water.

The specific needs of the facility and its product should be considered before selecting a level of filtration.

- In order to select the proper level of filtration, the water supplier must identify the contaminants in the source water and the desired level of treatment. For instance, a surface water supply that contains moderate levels of *Giardia* and *Cryptosporidium* would probably be well served with a microfiltration system. If the only available source water contained high levels of salt, a nanofilter or reverse osmosis system would likely be required.

Another aspect to consider when discussing the different levels of filtration is the pressure required to move water through the system. Microfiltration systems typically require between 15 – 40 psi in order to operate. Pressures gradually increase through each successive filtration level. The smallest pore size reverse osmosis filters can require between 800 – 1,000 psi to operate.

Flux

Flux is the flow rate through an individual membrane filter module expressed in terms of gallons of flow per square foot of membrane filter surface area per day.

When an operator discusses *flow rate*, he or she will typically say that the plant produces so many million gallons per day or so many gallons per minute. But, when discussing *filter operations* it is common to discuss flow in terms of gallons per minute per square foot of filter surface area (gpm/sq. ft.). **In membrane filtration, however, flow through a membrane filter is discussed in terms of gallons per square foot of membrane filter surface area per day (GFD).**

- Another difference in the way flow rates are expressed between conventional and membrane filters is that it is common to take the temperature of the feed water into account when discussing membrane flux.

Temperature corrected flux is used to discuss flux in terms of a standard feed water temperature. The standard temperature for this is 20°C (68°F). This term is useful for comparing performance between different manufacturers' membranes. It is usually expressed as gfd @ 20°C.

- As water gets colder, its viscosity increases.
  - A fluid with higher viscosity is more difficult to filter.
  - More pressure is lost through the filter when operating a membrane at a certain flux at 2ºC than it does to achieve the same flux at 20ºC. Bear in mind that the surface area of a membrane filter is not determined by the outside of the pressure vessel that houses the membranes but the area of the membranes themselves housed in the pressure vessel. Each pressure vessel can contain hundreds of square feet of membrane surface area. These concepts will be discussed at length in Unit 2.

To calculate flux, first figure the flow rate in gallons per day and then divide by the square footage of filter area.

Calculate the flux of a membrane filter if it contains 75 sq. ft. of filter area and operates for 24 hours at a flow rate of 5 gpm. Assume that the water temperature is 20°C.

Feed Water

Feed water is the influent water for the membrane system; it is the water being added to the membrane system itself.

- Feed water may not be water directly from the source.
  - For example, if the raw water is of poor quality, some membrane systems may utilize pretreatment steps prior to adding it to the membrane portion of the treatment plant.

Transmembrane Pressure

Transmembrane pressure is the change in the pressure of the water as it passes through the membrane. Transmembrane pressure is referred to as TMP by most manufacturers.

Specific Flux

Specific flux is the flux of the membrane divided by the TMP of the membrane itself. The lower the specific flux, the more pressure loss through the system and the more expensive it is to operate the system.

Temperature corrected specific flux for a membrane system is calculated by dividing a system's temperature corrected flux by the membranes' TMP.

To calculate specific flux, first calculate the flux, and then divide the flux by the TMP.

Calculate the specific flux of the system if it contains 75 sq. ft. of filter area and operates for 24 hours at a flow rate of 5 gpm. Assume that the water temperature is 20^{o}C and the TMP of the system is 20 psi.

Permeate

Permeate is the filtrate from a membrane filter. It is called permeate due to the way that the feed water permeates through the membrane.

Cross Flow vs. Dead End Flow

Cross flow means that a small portion of the feed water is allowed to flow across the surface of the membrane (rather than through the membrane).

- Cross flow tends to help clean the surface of the membrane and allows for longer operational periods between membrane backwashing or cleaning.
- Cross flow uses slightly more energy than dead end flow since some of the water being pumped into the module is not passing through the filter.
- Cross flow is usually used on feed waters of lesser quality or if pretreatment with powdered activated carbon is being used.

Dead end flow means that all of the feed water entering the membrane is passing through the filter.

Reverse Flow and Back Pulse

- In order to remove any material clogging the filter, a process analogous to backwashing must be conducted on a membrane filter.
  - Remember that headloss in a membrane filter is referred to as transmembrane pressure.

Reverse flow is the process of reversing the direction of water flow through the filter using permeate (filtered water). The permeate removes the material deposited on the surface of the membrane and the waste stream is collected and removed from the module.

- The procedure is also known as RF.

- RF is not as effective as traditional backwash procedures that are used on rapid sand filters.
  - For this reason, membrane filter systems occasionally must undergo a more rigorous chemical cleaning procedure.
  - This procedure will be discussed in greater detail in Unit 2.

Back pulse is a smilar process of reversing the flow direction, but is used on submersible types of membrane filter systems.

Another membrane manufacturer actually uses air pressure to pressurize the inside of each membrane fiber. The air is then released, causing the membrane to quickly collapse back to its original shape. As the membrane collapses, the material deposited on the surface is released. A water stream then carries this material out of the module.

Frequency and Duration

The frequency of the RF process is determined by the membrane filtration level selected, the characteristics of the membrane itself, and the quality of the feed water.

- RF frequencies of every 20 to 30 minutes are common in membrane facilities.
- Tighter membranes (RO and nanofilters) will generally require more frequent RF than the looser micro- and ultrafilters. This is because the tighter membranes are filtering out more particles, which in turn become trapped onto the filter and require RF to clear them.

The duration of the RF is determined by the membrane filtration level selected, the characteristics of the membrane itself, and the quality of the feed water.

Volume

As with the frequency and duration of the RF process, the volume used to complete an RF is also determined by the membrane filtration level selected, the characteristics of the membrane itself, and the quality of the feed water.

Percent Recovery

It is common in membrane treatment to refer to the efficiency of the treatment process by referring to the system's *percent recovery*.

- The percent recovery of a membrane system is the percent of the feed water that actually passes through the membrane, becomes permeate, and is not used to RF or otherwise clean the membrane.
- It is a comparison between the amount of water that enters the treatment system to the amount of water that is delivered to the distribution system.
- In a conventional treatment system, however, it is typical to discuss the percent wash water used.
- Micro- and ultrafilters (the looser filters) can achieve percent recoveries as high as 99% or as low as 80% or less, depending on water quality and operational practices.
- RO and nanofilters usually achieve much lower recoveries, sometimes as low as 60% or less.

What qualities determine the percent recovery in membrane treatment?

Concentrate or Reject

Concentrate, or **reject,** is the waste created from an RF of a membrane system.

- Rejection is the term used to define the percentage solute concentration reduction of the product water relative to the feed water in a membrane filtration process.

Air Scrub

Air scrub, or **AS,** is a process by which some membrane systems introduce air into the feed side of the filter module in conjunction with the RF process in order to enhance the RF's efficiency. The air agitates the surface of the membrane and enhances the removal of the material from the membrane's surface.

- This process can be conducted during every RF, or less frequently, as required.
- At least one manufacturer's submersible membrane uses a continuous air flow in the process tank to gently agitate the membrane fibers to help remove material from the surface of the membrane.

Backwash Recovery

Backwash recovery is a system in which the facility reclaims some or all of the RF waste from the system.

- These systems can include settling or filtration through a bag or cartridge filter system or through another membrane filter.
- After this treatment, the recovered water should be recycled back to the feed water side of the membrane filter system.

Chemical Clean-In-Place

Chemical Clean-in-Place (CIP) is a cleaning procedure that is used to restore the membrane's capacity to something near its original capacity.

- Each manufacturer has its own unique method to conduct CIPs, but there are similarities in the process.
  - CIP usually consists of allowing the membrane to soak in a relatively mild chemical solution.
    - This solution dissolves much of the material that could not be removed by the RF/AS process and removes it from the membrane's surface.
    - Some manufacturers heat the cleaning solution to enhance its impact.
  - Common methods also require (after the chemical soaking) rinsing the membrane, and then soaking it in a caustic solution.
    - At times, the cleaning solution is allowed to circulate through the filter.
    - These cleaning solutions are collected neutralized and discarded.
- The frequency of CIP should be kept to a minimum; a 30 day interval is considered an acceptable CIP frequency.

New Methodology

A recently developed procedure has been gaining favor in the world of membrane treatment. Since it is new, there has not yet been a consensus on the terminology for referring to this procedure.

Each manufacturer refers to it in different ways, but it is ultimately a mini chemical cleaning procedure. A solution of chemicals used to conduct the normal cleaning procedure are mixed, perhaps at the same concentration used for a normal chemical cleaning or perhaps at a lower concentration. The solution may or may not be heated. The cleaning solution is added to the membrane module and it is either circulated around the feed side of the membrane or the membrane is just allowed to soak in the solution.

The purpose of the CIP is to return the membrane to near its original condition, but the purpose of this mini-cleaning is to maintain the membrane in its current condition and increase the interval between CIPs. For this reason we will refer to this procedure as a maintenance chemical cleaning.

Unit 1 – Exercise

Multiple Choice – Choose the best answer unless otherwise noted:

1. Which of the following mechanisms is used by a membrane filter to remove particulate material from the water? (*Choose*)

   a. adsorption
   b. settling
   c. straining

2. The membrane filtration level with the smallest pore size (0.0001 – 0.001 µm) is called _____________. (*Choose one to fill in the blank*)

   a. microfiltration
   b. reverse osmosis
   c. nanofiltration

3. The flow rate through the membrane filter itself expressed as gallon per square foot per day is: (*Choose one to fill in the blank*)

   a. permeate
   b. headloss
   c. flux

4. Which one of the following is the name of the process of reversing the direction of water flow through the filter using filtered water? (*Choose one to fill in the blank*)

   a. back pulse
   b. reverse flow
   c. air pressure

5. The filtered water that has been treated by a membrane filter is called _____________: (*Choose one to fill in the blank*)

   a. permeate
   b. concentrate
   c. reject

6. Which of the following remains the primary use of membrane filtration in water treatment? (*Choose one to fill in the blank*)

   a. the desalination of salt water to produce potable water
   b. as a pretreatment step in water treatment
   c. for filtration of surface or ground water under the direct influence of surface water

Unit 1 Summary

Key Points:

- Which material will pass through the membrane is determined by the size and the chemical characteristics of the membrane and the material being filtered.
- Particulate removal in the microfiltration process is through size exclusion, except for larger molecular substances such as humic and fulvic acids. Adsorptive affinity can influence removal of these molecules.
- When membrane filtration is used as the only treatment process, fairly high-quality source water is usually required.
- Surface waters are generally more difficult to treat than highly organic groundwater using the membrane filtration process due to the increase fouling potential of surface water.
- Membrane filtration is a mechanical filtration technique which comes as close to offering an absolute barrier to the passage of particulate material as any technology currently available in water treatment.
- Reverse osmosis has the highest operating pressure of all the membrane filtration processes.
- In membrane filtration, the term rejection is used to define the percentage solute concentration reduction of the product water relative to the feed water.
- CIP stands for Clean In Place. CIP usually consists of allowing the membrane to soak in a relatively mild chemical solution so it can dissolve material on the membrane not removed through normal backwashing.

Unit 2 – Membrane System Materials, Configurations, and Operation

Learning Objectives

As a result of this unit, the learner will:

- Review the major components of a membrane filter system.
- Compare the three methods of pretreatment that can be used in a membrane filtration system.
- Examine forms of membrane filters, membrane system configurations, and flow paths.
- Receive a description of the five automatic procedures that can be automatically implemented for membrane filtration systems.

Membrane System Components

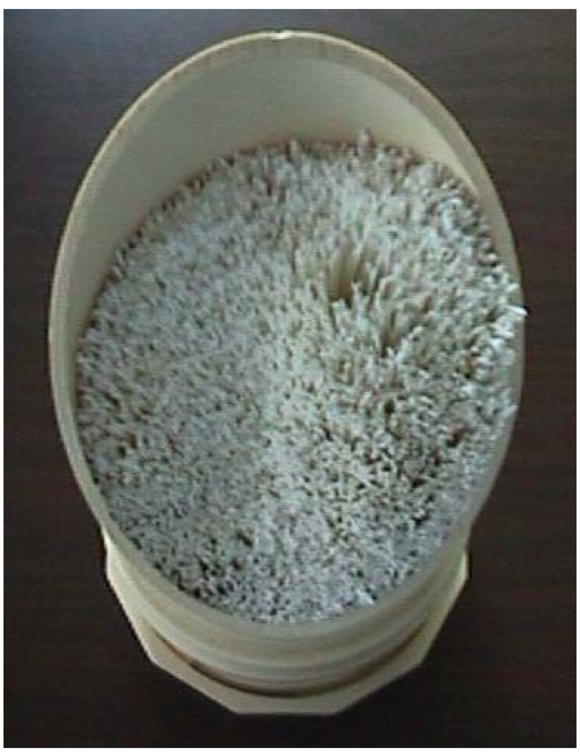
There are four components in a membrane filtration system: membranes; modules; racks; and piping.

Membranes

- The membrane itself is usually quite small.
- The most common type used in water treatment resembles a very thin straw.
- Membranes are made of a variety of materials, but usually are from organic compounds.
- Some membranes are made from proprietary compounds.

Figure 2.1 Individual Membrane Fiber

Modules



- Thousands of membranes are gathered together and placed inside a vessel.
  - Vessels are usually pressure vessel models.
  - Vessels are usually created from PVC or similar materials.
- Each pressure vessel containing the individual membranes is referred to as a module.

Figure 2.2 Membranes Gathered into a Module

Racks

- A number of modules are placed onto a membrane filter rack.
- The rack delivers the influent, collects the effluent, and distributes the RF, AS, and CIP chemicals.
- A membrane filtration system consists of one or more of these racks.
  - Individual racks may suffice for low flows.
  - More racks are needed for higher flows.

Figure 2.3 Rack Configuration

Piping Systems

- Influent and effluent piping can be made of any material that is suitable for water treatment unless that piping is also used to carry CIP chemicals to and from the racks.
  - In the case of chemical transport, the pipe material should be compatible with the chemicals being transported.
- Membrane filtration plants require air piping to supply the air necessary to conduct the AS process.
  - Stainless steel is frequently used for air piping.

Chemical Tolerance

- It is important to consider the chemical tolerance of membranes.
  - Not all membranes are chemically resistant to all of the chemicals that may be present in the feed water.
    - Chlorine from chlorinated feed water might damage membranes.
    - Organic chemicals, such as solvents in feed water, might damage membranes.
    - Acidic or basic pH might damage certain membranes; if these types of membranes are used, remember to confirm that the feed water and CIP procedure will not harm the product.

Forms of Membrane Filters

Several forms are available for membrane filters: hollow fiber; spiral wound; ceramic; and EDR membranes.

Hollow Fiber

- Hollow fiber membranes are very common.
- This configuration is used primarily for microfiltration and ultrafiltration membranes.
- Hollow fiber membranes resemble a thin straw with holes in the side and at one end.
    - The open section in the center of the straw is called the lumen.
    - The holes along the side are the pores through which the water passes during filtration.
    - The hole at the end is used to distribute the influent or collect the effluent, depending upon the flow path used.

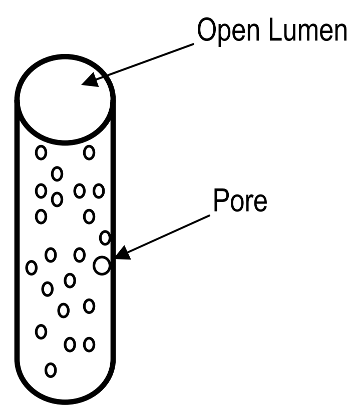


Figure 2.4 Hollow Fiber Membrane

Spiral Wound

- Spiral wound membranes are commonly used.
- This configuration is used primarily for RO filtration membranes.
- Two “sheets” make up the configuration.
  - The top sheet allows feed water to flow on it and permeate through it to the bottom sheet.
  - The bottom sheet is impermeable and is called the permeate carrier.
    - The permeate carrier carries the permeate from the membrane out of the filter.
- The combination of the membrane and the permeate carrier make up an envelope.
  - Many envelopes create a spiral wound membrane module.
- The envelopes are attached to a central core, the permeate tube.
  - The permeate carrier sheet carries the permeate to this tube.

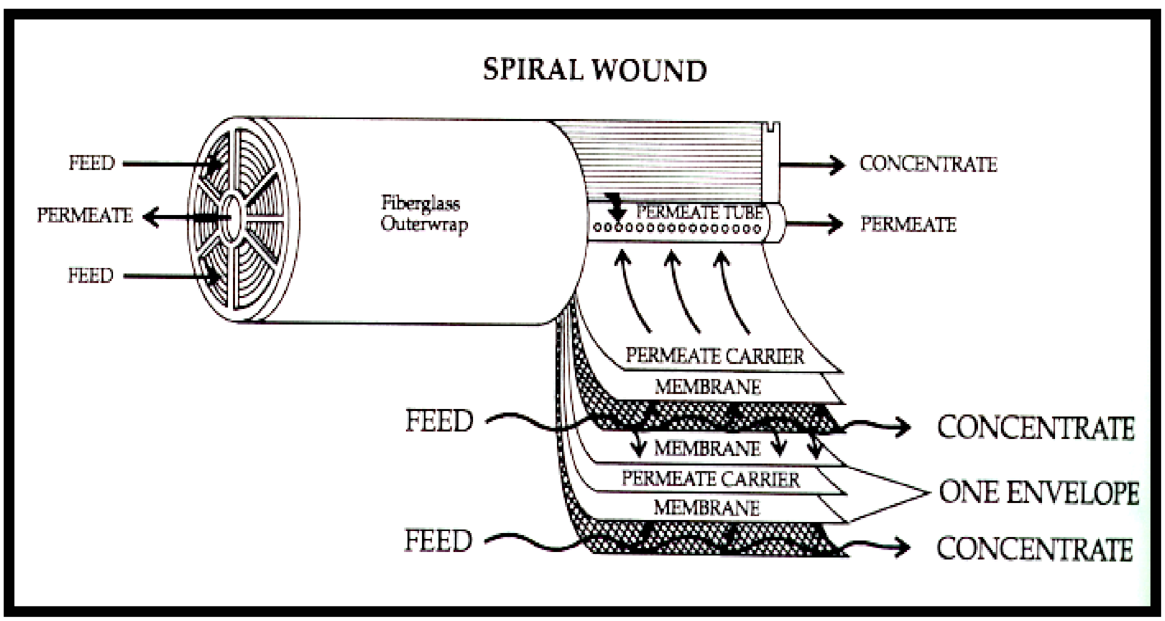


Figure 2.5 Spiral Wound Membrane[1]

Ceramic and Other Materials

- Membranes can be constructed from a variety of materials.
- Ceramic is a typical material used for these constructions.
- Backpacker water filters may use ceramic membranes to filter the water.
- These are not commonly found in water treatment facilities.

Electrodialysis, or ED

- ED is an electrically driven process, rather than the typical pressure driven process.
- Electrical force moves only the ions and the associated water to the membrane rather than the entire solution, as would happen in a pressure driven system.
- ED is used for desalinization and deionization of water for industrial uses; it is not widely used for potable water treatment.

Membrane System Configurations

Membrane treatment systems are either pressure driven or vacuum driven. There are some significant differences between the two.

Parameters	Pressure Driven Systems	Vacuum Driven Systems
Operations	A vessel is required in order to maintain pressure.	Membranes are immersed in a tank that contains feed water.
Pumping	A pump forces the feed water into the pressure vessel.	The pump is on the discharge side of the membranes to pull water from the tank in which membranes are submersed.
Membranes	Hollow fiber or spiral wound membranes are used.	Only hollow fiber membranes are used.

Flow Path

Hollow Fiber

Two possible flow paths are available for hollow fiber membranes.

- If feed water is introduced to the inside of the fiber and allowed to flow through the membrane to the outside, it is referred to as inside-out flow.
- If feed water is added to the outside of the fiber and flows through the membrane to the inside, it is referred to as outside-in flow.
- There is no significant difference in the performance of these two flow paths.

When calculating the flow rate through a hollow fiber membrane system, it is important to know the flow path through the fiber. The flow rate is calculated by dividing the flow by the surface area of the membrane. In the case of an inside-out flow path, the inside diameter of the fiber is used for calculations. In the case of an outside-in flow path, the outside diameter of the fiber is used to calculate the surface area of the fiber.

Spiral Wound

- The feed water that is not carried into the permeate tube stays on the feed side of the membrane and travels to the other end of the membrane module.
  - This stream is referred to as concentrate.
- Spiral wound membranes tend to be less efficient than hollow fiber membranes.
  - To increase their efficiency, they use a number of different flow paths.
    - In some cases, the concentrate is recycled back to the feed side of the membrane element and is allowed to pass through the membrane element again. This is a multiple pass system.
    - More commonly, a number of spiral wound membrane elements are configured into a membrane array. The array functions by taking the concentrate from the element(s) at the head of the array and passing it through secondary elements.
    - The secondary element(s) in the array operate at much lower flux rates than the primary elements.
    - Arrays are usually arranged in configurations referred to as 2 by 3 (meaning 2 primary elements and 3 secondary elements) or 2 by 2 by 1 (2 primary elements, 2 secondary elements, and 1 tertiary element).
  - By passing the concentrate through multiple elements, the recovery of spiral wound systems can be improved significantly.

Pretreatment

Not all source waters are suitable for treatment using membrane filtration. In some cases, pretreatment of the source water may improve the quality sufficiently to allow for the use of membrane filtration.

Pretreatment can be a prefiltration step to remove particulate matter or it can be some type of chemical treatment to remove or alter substances that might have contributed to membrane fouling. An anti-scalant or acid addition can be used.

- The silt density index is used to estimate membrane fouling.

Establishing the Need for Pretreatment

Use these three points to establish the need for pretreatment.

- Examine the historical feed quality records.
- Examine pilot scale evaluations on the feed water.
- Keep in mind the utility's water quality goals.

If a source water has high hardness and high turbidity levels, and the utility wishes to soften the water, what pretreatment functions might be appropriate?

Methods of Pretreatment

Four types of pretreatment are available to make water suitable for membrane filtration: filtration; clarification; chemical treatment; and a combination of one or more of the methods.

Filtration

- Virtually 100% of all membrane filtration systems employ some type of prefilter in the process.
- Prefiltration can be accomplished by bag or cartridge filters, strainers, or another looser membrane filter.
    - In large systems, where so many filters would be expensive to replace regularly, strainers are a viable alternative.
        - Strainers are available in a variety of mesh size openings.
        - Many strainers automatically backwash themselves as necessary during operation.
    - Using a looser membrane prior to using a tight membrane is frequently practiced in RO systems.
        - Source water is microfiltered or ultrafiltered prior to undergoing nanofiltration for RO. This arrangement is referred to as an integrated membrane process.

Clarification

- Clarification can be accomplished with or without the use of chemicals.
    - A simple clarification process would include a raw water reservoir.
    - A more complex procedure might involve using a high rate clarification process.

The goal of the clarification process is to reduce the loading and the fouling potential of the water fed to the membranes. Therefore, it is important that the clarification process itself not degrade the feed water quality.

A source water is placed in a reservoir to reduce high turbidity. What effects could this have on the feed water quality as it applies to membrane filtration?

A facility uses a high rate clarification process that utilizes a polymer to enhance settling. Could this have any negative impact on the membrane filtration process?

Chemical Treatment

Three common chemical treatments involve oxidant addition, coagulant addition, and powdered activated carbon addition.

Oxidant Addition

- Oxidant addition can oxidize soluble material from the feed water and improve its removal on the filter.
- It can also destroy any algae that may be present in the feed water.
- It can destroy harmful synthetic chemicals that might not be removed by the membranes.

Coagulant Addition

- Some substances, such as fine colloids or clays, may not be well removed by the loosest membranes or they may penetrate into the pores of the membrane and become difficult to remove.
- Coagulants encourage these substances to form larger particles that might be more easily removed on the membrane surface.
- The coagulant, however, can cause the filter to become clogged more rapidly than in filtration without coagulant additions.
    - A thorough evaluation of the treatment—pros and cons—should be completed prior to implementation.

Powdered Activated Carbon (PAC) Addition

- PAC is quite effective at absorbing organic compounds from water.
- PAC can be added prior to the filter in order to absorb organic chemicals, taste, and odor; the PAC itself would then be removed on the surface of the membrane during filtration.
- Note that the addition of PAC will likely decrease the flux rate and increase the TMP of the system.

System Limitations

As in any other treatment process under consideration, the limitations of this system must be considered when examining the feasibility of using membrane filtration.

Pressure

- The pressure vessels in a pressure driven system have a maximum allowable inlet pressure, which is usually well above any pressure that is commonly seen in a water plant, but should still be a factor to consider.
- The membrane filters may have a limited pressure capacity above which damage to the membrane will occur.
- Compaction, the compression or densification of a membrane as a result of exposure to applied pressure over time, will reduce the flow rate across the membrane.

Flux

- If more flow is needed than a membrane filter's maximum flux allowance, more membranes must be added.
  - This increases the costs of a membrane filtration system.
  - At some point, the costs will increase to the point that it may be economically unfeasible to use membrane treatment.

Chemical Tolerance

- If chlorine and other organic chemicals or solvents that destroy some membranes cannot be removed prior to reaching the membranes, another type of membrane or another type of treatment should be considered.

Automatic Procedures

A membrane filtration system has a control system that can automatically implement and conduct five procedures: flux maintenance; RF; maintenance chemical cleaning; cross flow maintenance; and membrane integrity testing.

Flux Maintenance

- The desired flux rate must be established, and then that information is entered into the operating system. Membrane filtration systems are capable of maintaining a flux rate during normal operations.

- The flux rate achievable by a membrane filter is determined by the feed water quality. The system's design flux rate is established through feed water quality evaluations and pilot testing. This information is used to design the membrane filtration system.

- Once the flux rate is determined, this information is programmed into the membrane system's control logic. The membrane system will then operate the membrane racks at the necessary rate to maintain the desired plant production.

- The operator's responsibility is to confirm that the control system is operating properly and that the membrane system's production is sufficient to meet system demand. The operator can adjust the membrane flux rate as necessary by manipulating the control system of the unit.

Reverse Flow (RF)

- One of the ways to keep the membrane clean is the RF process. The procedure, frequency, and duration of the RF process are somewhat manufacturer specific, but they are more dependent on the quality of the feed water.

- Pilot testing will help to establish the frequency and duration of the RF. However, occasional adjustments to these parameters may be necessary due to changes in feed water quality or membrane condition. These parameters are easily adjusted using the system's control logic.

- Some procedural changes to the RF cycle may be field-programmable as well. The addition or modification of an air scrub cycle or RF flow rate may be possible, but is dependent on the level of sophistication of the treatment system.

Maintenance Chemical Cleaning

- Depending on the procedure and chemicals that are used to conduct the cleaning, it can be conducted on an automatic, routine basis.

- Feed water quality and system performance can be used to determine the frequency and duration of this procedure.

Cross Flow

- Cross flow tends to help clean the surface of the membrane and allows for longer operational periods between membrane backwashing or cleaning.
- The need for operating in the cross flow mode is assessed from feed water quality evaluations and pilot testing results.
- The amount of water used for a cross flow is adjustable. The percent of the feed water used to cross flow can be anywhere from 1 to 50% depending on the feed water quality and level of filtration.
- When the need for cross flow and the percent required are established, the system will maintain this level.
- Field-adjustments to this system are possible and would be dictated by a change in feed water quality or pretreatment.

Membrane Integrity

There are several methods that are used to conduct this testing; they can be divided into two categories.

Direct Method

- An air pressure hold test consists of pressurizing one side of a hollow fiber membrane module, and then watching the air pressure decay for several minutes.
    - If the membrane fibers in the module are intact, the pressure decay will be very slight.
    - If a membrane in the module has been broken, the pressure decay will be very apparent.
    - Each manufacturer has its own criteria for the amount of pressure that should be applied to the module and the acceptable pressure decay, but an intact membrane will hold nearly all of the pressure applied to it.
- Most hollow fiber membrane systems are capable of automatically conducting an air pressure hold test. This procedure is conducted on an entire rack of modules at one time and is capable of finding one broken fiber in all of the modules on the rack. The required air pressure hold testing frequency is determined by the regulatory agency.

  Note that this test can only be used on hollow fiber membranes. Due to the way that spiral wound membranes are constructed, an air pressure hold test can not be used. While this might appear to preclude the use of spiral wound membranes for surface water treatment, the vast majority of spiral wound membranes are used in nanofiltration or RO applications and all nanofiltration or RO treatment of a surface water source must be preceded by some type of pretreatment. This pretreatment is predominately achieved by using a hollow fiber micro- or ultrafilter.

Indirect Methods

- Indirect integrity testing typically includes on-line turbidity and/or particle counting.

- When a membrane is compromised, it will begin to pass more particulate material through the broken portion of the membrane. If only a few membrane fibers are compromised, you may not be able to detect an increase in turbidity or particle counts, which is why direct methods are important. However, when membrane failure becomes significant an increase in particulate material passing through the failure zones will cause an increase in permeate turbidity and particle counts, indicating that integrity has been lost.

I

Manual Procedures

Two functions are commonly practiced through manual procedures: CIP and membrane fiber repair.

Chemical Clean-in-Place (CIP)

- Recall that CIP is a procedure that is used to restore the membrane's original productivity, which is also known as the membrane's specific flux.
  - Specific flux is the flux of the membrane divided by the membrane's TMP.

- The goal of the CIP is to return the membrane to close to its original TMP while operating at the desired flux rate.
  - However, no cleaning process is 100% effective, so it is very unlikely that the membrane will return to its original operating conditions regardless of the cleaning process used.

- Cleaning procedures are completed on an entire rack of membrane modules at one time.

CIP Initiation Criteria

- The interval between chemical cleanings is determined by the feed water quality and the maximum TMP at which the system can be operated.
  - The most frequently used criterion is TMP.
  - Recall that TMP is the amount of pressure lost as the water passes through the membrane.

- All manufacturers have established a maximum TMP.
  - Operating the system in excess of this maximum could damage the membrane or associated equipment.

- Some facilities may choose to conduct CIP based on the time interval from the last CIP, although this is not common.

Cleaning Solutions

- The type of cleaning solution used is dependent upon the material from which the membrane is made and the nature of the material to be removed.

- Some chemicals from which cleaning solutions are made are chlorine, acids, bases, surfactants, or a combination of these chemicals.

- The manufacturer specifies the chemical and solution strength to be used for CIP.
  - Some manufacturers may require the use of proprietary chemicals to conduct CIP.

Cleaning Methods

The manufacturer will provide the CIP method to be used for its equipment. These methods can be modified to enhance the CIP performance, although any modifications should be approved by the manufacturer prior to implementation. Slight changes in CIP procedures could severely damage the membranes.

- Frequently, the cleaning solutions are heated to improve the performance of the CIP.
  - Heating the cleaning solution tends to increase the rate of reaction and improve CIP performance.

- Some manufacturers circulate the cleaning solutions through the membranes.

- Other procedures call for the membrane to be allowed to soak in the cleaning solution for extended periods of time.

- Some procedures utilize a combination of soaking and circulation to maximize the CIP effectiveness.

- Regardless of the method used the CIP procedure can be somewhat labor intensive.

Cleaning Efficiency

How can the operator determine how effective the CIP procedure is at restoring the membrane's original specific flux? The effectiveness of the CIP can be quantified by calculating the system's loss of original specific flux. This calculation can be made by using the following equation:

Loss of original specific flux = 100 X $(1 - (Js_i / Js_{io}))$

Where: Js_i = Specific flux (gfd/psi) when the system was restarted after completion of the cleaning procedure (initial), and
Js_{io} = Specific flux (gfd/psi) at time zero point of membrane testing

At some point the CIP procedures will be unable to recover enough of the original capacity of the membrane system to maintain efficient operations. At this point, replacement of the membrane modules will be necessary.

Neutralization and Disposal

Several methods can be used to dispose of the cleaning solution.

One method is to recycle the CIP solution.

- A cleaning solution can be reused a number of times.
- As mentioned earlier, cleaning is conducted on an entire rack of membranes at a time.
  - Practically all membrane facilities will have at least two racks of modules and some extremely large facilities could have 10 or 20 racks full of modules.
  - After the first rack has been cleaned, the cleaning solution can be stored and used to clean another rack or other racks of membranes.
    - If this is done, the cleaning solution may need to be filtered to remove any particulate material that was removed from the first membrane rack.
    - The cleaning solution may also need to be fortified prior to its reuse.
      - For instance, if a chlorine solution is used for CIP some of the chlorine residual may have dissipated during the first cleaning. Additional chlorine will need to be added to the solution to return the chlorine residual to its desired level prior to initiating the second CIP.
- The recycling procedure can be used to refortify acid or caustic solutions prior to reuse.

Before disposal, it may be advantageous to neutralize the spent CIP solution.

- Although cleaning solutions are not usually extremely hazardous, they may have a pH of 3 or less or 12 or more or they could contain significant levels of chlorine (200 – 300 mg/l).
  - If so, it may advisable to neutralize these chemicals prior to disposal.
    - Neutralization of an acid can be done using a base (caustic solution); alternately, a base can be used to neutralize an acid..
    - Some membrane systems actually use both acid and base during CIP, and the two spent cleaning solutions can be used to neutralize one another.
    - Spent chlorine cleaning solution can be neutralized with any of a number of dechlorinating agents.

After neutralization, the spent CIP solution will need to be discarded.

- The best method for discarding this solution will be site specific.
  - If there is a sewer connection available and the wastewater plant is agreeable, disposal to the sewer system is an option. This is probably the least expensive disposal option.
  - If there is not a sewer connection available, hauling of the spent CIP solution to the WWTP may be an option.
  - At worst, the waste may be taken to a landfill that will accept it.

Membrane Repair

Membrane repair is the second type of manual procedure. Three steps are needed to accomplish this repair: locating the compromised module, finding the broken fiber(s), and repairing the fiber(s).

Locating the Compromised Module

- As previously discussed, the on-line integrity tests scan an entire rack for compromised fibers.
  - The control system will automatically take the entire rack off-line when the rack fails the integrity test.
  - It is the operator’s job to find out which module in the rack has the broken fiber.

- Fortunately, most manufacturers have included some type of “tattle-tale” device to indicate which module on the rack contains the broken fiber.
  - If a “tattle-tale” is not included it may be necessary to valve off each individual module on the rack and re-conduct the integrity test until the compromised module is located.

Finding the Broken Fiber(s)

- The first step is to drain the module.
- Remove the module from the rack.
- Place it in a cradle or some other device to support the module. (Some manufacturers supply module testing stations with their equipment.).
- One of the end caps of the module is then removed and the module is pressurized with air.
- The operator can then observe the end of the module where the fibers are attached to the module.
- At this point the broken fiber will be readily apparent; it is the one that the water and air is gushing out of!
- The operator can then mark the location of the broken fiber.
- Remember that there could be more than one broken fiber in the module and that, depending on the style of module, both ends of the module may need to be observed.

Repairing the Fiber

- The fiber is actually not repaired; it is sealed off so that no water will flow through it.
    - The fiber is actually simply being eliminated from use.
- The “repair” method varies somewhat from manufacturer to manufacturer, but they all consist of plugging the broken fiber with some type of pin and then gluing it into place. This process is repeated until all of the broken fibers have been plugged.

Membrane Replacement

- The RF and CIP processes are not 100% effective.
    - Eventually sufficient un-removable material will accumulate on the membrane so that it can not operate at the required flux rate. The membrane is referred to as irreversibly fouled, and it must be replaced.
- The inlet and outlet fittings are removed.
- Any supports or other connections are removed.
- Then the module is removed from the rack.
- The removal process is reversed to install the new module.
    - Prior to placing the new module into service, it will be necessary to “wet” and rinse the membrane.

System Startup

- The target flux rate will have been established prior to system startup.
  - During startup, the flux rate will likely be ramped up to the target flux rather than started at the target rate.
    - This ramping up could take days or weeks to complete.
  - Likewise, during startup individual filter racks will be started one at a time rather than all at once.

- Filter-to-waste of the permeate is necessary during plant startup.
  - This will remove any remaining preservative that may have been used on the modules for shipment and will waste any extraneous material that may have been left behind during the production of the module.
  - After system startup, filter-to-waste cycles will be required after CIP or module replacement.
  - Filter-to-waste cycles after RF are not necessary in membrane systems.

Daily Process Monitoring

Flux

- The control system will maintain the desired flux through the membranes.

- The operator should confirm that the system is operating at the desired flux throughout the day.

- He/She should also review historical operator data from the previous few days.

- The control system functions by using signals from flow meters to indicate the need to increase or decrease pump speed or valve positions to maintain the desired flow through the meter.
    - Therefore, the information being displayed by the control system is only as accurate as the flow readings it is receiving.
    - It is important to maintain and calibrate the flow meters. The frequency for these tasks will be discussed in a subsequent section.

TMP

- The TMP of the membrane modules or racks of modules should be closely monitored by the operator; system TMP is probably the most important parameter used to monitor system operation.

- Gradually increasing TMPs are normal and usually indicate that the system is operating acceptably.

- On the other hand, if system TMPs show a sudden rapid increase, it could alert the operator to problems with the feed water quality or pretreatment system.

- A sudden decrease in system TMPs (not related to a CIP) may indicate a failure of one or more modules or a failure of the pressure monitoring system.

Turbidity

- Feed water and permeate turbidity should be monitored multiple times during the day.

- Changes in feed water turbidity could indicate changes in feed water quality or in the pretreatment system that could impact the operation of the membrane system.
    - Significant increases in the permeate turbidity could jeopardize the plant's ability to comply with SWTR regulations.
    - Significant increases in the permeate turbidity could also indicate a failure of fibers or entire modules in the treatment system.

Particle Counts

- Feed water and permeate particle counts should be monitored at least daily.
- Changes in feed water particle counts could indicate changes in feed water quality or in the pretreatment system that could impact the operation of the membrane system.
- Significant increases in the permeate particle counts could indicate a failure of fibers or entire modules in the treatment system.

Chlorine

- Membranes are often adversely affected by chlorine.
- Finished water chlorine residuals should be monitored multiple times during the day.
- The treatment facility will be required to maintain a minimum amount of chlorine in the finished water.
    - Failure to maintain this minimum level would be a violation of drinking water regulations.
- Significant changes in feed water chlorine residual may indicate a change in feed water quality or pretreatment system performance.
- For surface water systems, the required residual disinfectant concentration may not be less than 0.2 mg/l for more than four hours before the first customer/
- A significant change in finished water chlorine residual could indicate problems with the membrane filters themselves.

Weekly Process Monitoring

On-line Analytical Equipment

- The proper operation of the on-line analytical equipment should be verified at least weekly.
- Verifying proper flow rates and the accuracy of the readings is critically important to the operation of a water treatment facility.
- Recommended flow rates will be listed in the manuals provided with the equipment.
- Accuracy of the readings can be determined by comparing the on-line analyzer's readings to the results obtained from a calibrated bench-top instrument.

Exercise

Unit 2 Exercise

Multiple Choice – Choose the best answer unless otherwise noted:

1. Select all the different forms of membrane filter construction? (*Choose all that apply*)
   a. hollow filter
   b. TMP
   c. spiral wound
   d. ceramic
   e. cross flow
   f. electrodialysis

2. A raw water reservoir would be an example of which membrane pretreatment method (where the goal is to reduce the loading and fouling potential of the water fed to the membrane)? (*Choose one*)
   a. filtration
   b. clarification
   c. chemical treatment

3. Which of the following is a valid name for a test for testing membrane integrity? (*Choose one*)
   a. flux membrane test
   b. reversal of flow test
   c. air pressure hold test

4. Chlorines, acids, and bases are three types of chemicals used to do which of the following? (*Choose one*)
   a. prescreen the water in the membrane filtration system
   b. chemically clean a membrane filtration system
   c. monitor a membrane filtration system for fiber failure

5. Select all the operational items that should be monitored on a daily basis for a membrane filtration system: (*Choose all that apply*)
   a. flux
   b. reverse flow
   c. particle counts
   d. chlorine
   e. cross flow
   f. TMP
   g. turbidity

6. For surface water system, the required residual disinfectant concentration may not be less than _______mg/L for more than ___________hours before the first customer.

   a. 0.2, 6
   b. 2.0, 6
   c. 0.2, 4
   d. 2.0, 4

Matching – Match the membrane filtration parts with the corresponding description:

7.	_______	Rack	A.	A number of modules placed onto one of these, and a membrane filter systems consist of one or more of these.
8.	_______	Membrane	B.	Thousands of membranes are gathered together and placed inside of one of these.
9.	_______	Vessel	C.	The most common type used in water treatment resembles a very thin straw.
10.	_______	Module	D.	This carries the influent and effluent.
11.	_______	Piping	E.	Each pressure vessel containing the individual membranes is referred to by this term.

Unit 2 Summary

Key Points:

- It is important to consider the chemical tolerance of membranes. Chlorine adversely affects microfiltration membranes.
- When membrane filtration is used as the only treatment process, fairly high-quality source water is usually required.
- A prefilter can remove large particulate matter in the water prior to the filtration.
- Membrane filtration is a mechanical filtration technique which comes as close to offering an absolute barrier to the passage of particulate material as any technology currently available in water treatment.
- The driving forces for hollow fibers in the membrane filtration can be positive of negative pressure. The direction that the feed water flows can be inside out or outside in for both pressures.
- Compaction in the filtration process causes flux decline.
- The silt density index is used to estimate membrane fouling.
- Fouling of membranes due to scaling can be reduced by pretreating raw water with an anti-scalant or by acid addition.
- The two test methods that are used to test system integrity are direct and indirect.
- A pressure decay test is a method used to evaluate the membrane’s integrity.
- Filter turbidity is monitored to evaluate overall process performance.

[1] Ando Masaaki, "Backwashable Spiral Wound Ultrafiltration Membrane," http://www.nitto.com/rd/2001_1/06anndou3e.qxd.pdf, accessed 16 Jun 2003.

Unit 3 – Regulatory and Economic Issues

Learning Objectives

As a result of this unit, the learner will:

- Review the treatment techniques that may be employed in conjunction with microfiltration or ultrafiltration to reduce the formation of disinfection byproducts.
- Examine the various items that determine the cost of operating a membrane filtration system.
- Receive a description of membrane filtration techniques that can be used to remove radon and arsenic from the source water.
- Obtain an explanation of the impact of the filter backwash rule on the recycling of membrane washwater.

Surface Water Treatment Rules

- Membrane filtration can be used to comply with the requirements of the various SWTRs.
  - The Interim Surface Water Treatment Rule was enacted to primarily control turbidity.
  - Even the loosest membranes, micro- and ultrafilters, can produce water that is free of *Giardia* cysts and *Cryptosporidium* oocysts.
    - They will also produce a permeate that will comply with SWTR turbidity requirements.
  - Certainly, the tighter membranes, nanofilters and reverse osmosis systems, would be capable of removing *Giardia* cysts and *Cryptosporidium* oocysts.
    - They produce a permeate with an acceptable turbidity.
- Since spiral wound filters can not be integrity tested, using a spiral wound RO filter alone for compliance with SWTR may not be permitted.
  - As mentioned in a previous unit, RO filters almost always require some type of pretreatment of the feed water; this pretreatment frequently consists of a micro-or ultrafiltration system, so these filters could be used to achieve compliance with the SWTRs and the RO filter could be used to remove other undesirable material from the water.
- A 3-log removal means removing 99.9% of a target organism.

Disinfection Byproducts

In order to reduce the amount of disinfection byproducts (DBPs), the operator must reduce the amount of the precursors in the water or minimize the amount of chlorine used.

Microfilters and Ultrafilters

- Micro- and ultrafilters may be capable of reducing the formation of DBPs in the finished water.
  - Most organic precursors tend to be dissolved in the feed water, so their removal would be limited at best with a micro- or ultrafilter.
  - Micro- and ultrafilters have been used in conjunction with PAC feed to enhance DBP removal.
  - PAC is added to the feed water where it begins to absorb the soluble precursors.
  - The PAC is then removed on the surface of the membrane.
- Another possible treatment technique for DBP reduction using micro- and ultrafilters involves the filters' ability to achieve very high removals of *Giardia* cysts and *Cryptosporidium* oocysts.
  - Micro- and ultrafilters have been shown to achieve very high removals of Giardia cysts and Cryptosporidium oocysts so the use of these filters would satisfy requirements without the use of excessive amounts of chlorine.
  - Also, micro- or ultrafiltered water would tend to have significantly lower chlorine demands.

Nanofiltration and Reverse Osmosis

- Nanofiltration and reverse osmosis systems will function in the same way as micro- and ultrafilters regarding the removal of particulate precursors and allowing for the reduction of the amount of chlorine added to the water.
- The use of PAC with a nano- or reverse osmosis filter is not recommended.
- These filters will also remove dissolved organic precursors from the feed water, thereby lowering the amount of DBPs that can be formed.
- The product water of a membrane filtration process using reverse osmosis and nanofiltration is corrosive because ions are removed that reduce the buffering capacity of the water.

Radon

- Radon removal using membrane filtration may be possible, depending upon the level of filtration used and the nature of the radon in the feed water.
- Micro- and ultrafiltration would probably have no effect unless the radon is associated with particulate material.
- Nanofiltration or RO could remove radon, but they would not be cost effective when compared to other treatment techniques.

Arsenic

- Micro- and ultrafilters would be ineffective in removing arsenic unless the arsenic is associated with particulate material in the feed water.
- The filter methods could be effective if combined with some type of coagulation process that would coagulant the arsenic out of solution and then be removed on the filter.
- Nanofilters and RO can remove arsenic but may not be the most cost effective option.

Filter Backwash Rule

- Micro- or ultrafilters could be used as a treatment method prior to recycling backwash waste in conventional treatment plants.
- They could also be used to treat RF water prior to recirculation to the head of the membrane plant.
- Nanofilters and RO could be used for backwash waste treatment, but it would not be cost effective and this level of filtration would be unnecessarily fine.

The costs of operating a membrane filtration facility are dictated by the flux rate at which the system can operate, the required system head pressure, and the frequency and cost of membrane replacement.

Flux Rate

- Higher flux rates mean fewer modules will be required.
  - This will save money during the plant construction and can reduce the amount of maintenance the system will require.
- Remember that the flux rate is determined by the quality of the feed water and the effectiveness of the pretreatment process, if used.
- One negative aspect to operating at high flux rates is that it may tend to shorten the life span of the modules.
  - Module replacement may be the most significant maintenance cost in a membrane treatment facility.

TMP

- Another factor in determining the cost of operating a membrane treatment system is the system head pressure.
  - A membrane system must also overcome the pressure drop through the filters themselves.
- A membrane filter's TMP can be 30 to 40 psi prior to CIP; this is a significant amount of pressure to overcome and will cause the pumps delivering water to the membrane to draw a great deal of power.
  - Increasing the amount of electric power needed to operate the system will increase treatment costs.

Membrane Replacement Frequency

- The frequency and cost of replacing membrane modules helps to determine membrane system operating expenses.
- The RF, CIP, and maintenance chemical cleaning are not 100% effective at removing the material that is deposited on the membrane so, at some point, module replacement will be necessary.
  - Replacement is an expensive and labor intensive operation.
- It is common for membrane modules to last 10 years or more before needing replacement, although the life depends upon feed water quality, flux rate, and cleaning effectiveness.

Exercise

Unit 3 – Exercise

Fill in the blank:

1. The Interim Surface Water Treatment Rule was enacted for the control of_____________.

2. A 3-log removal of organisms means ______________ % removal of target organisms.

3. ___________ addition and ____________ reduction might be employed in conjunction with micro- or ultrafiltration to reduce the formation of disinfection byproducts.

4. __________________ and _______________ membrane treatment processes that may be used to remove radon from a source water, even though they may not be cost effective treatments.

5. The cost of operating a membrane filtration system is determined by _______ rate attainable, rate of _______increase, and membrane replacement frequency.

6. The product water of a membrane filtration process using reverse osmosis and nanofiltration is corrosive because __________ are removed that reduce the ______________ capacity of the water.

Unit 3 Summary

Key Points:

- Membrane filtration can be used to comply with the requirements of the various surface water treatment rules.
- PAC addition and chlorine reduction may be used in conjunction with microfiltration or ultrafiltration to reduce the formation of disinfection byproducts.
- Nanofiltration or RO can remove both radon and arsenic, but they may not be the most cost effective options for removing these contaminants.
- Microfiltration or ultrafiltration can be used as a treatment method prior to recycling backwash water in conventional treatment plants.
- The costs of operating a membrane filtration facility are dictated by the flux rate at which the system can operate, the required system head pressure, and the frequency and cost of membrane replacement.

Unit 4 – Maintenance and Recordkeeping

Learning Objectives

As a result of this unit, the learner will:

- Review the maintenance activities and procedures needed to properly maintain a membrane system.
- Examine the various issues that should be examined when determining the cause of a rapid increase in the membrane filtration system TMP.
- Receive a description of items that may indicate a compromised fiber in a membrane module.
- Obtain an explanation of the two types of membrane fouling and their differences.
- Review the operational and maintenance records that should be maintained for a membrane system

Prefilter

- If the prefilter is a simple bag or cartridge filter, maintenance would include replacing the filters when their capacity has been exhausted.
  - It is prudent to check the condition of the O-rings and housing.
  - Check the condition and accuracy of the pressure gauges on a regular basis.
- If a more complex prefilter is used (such as a backwashable strainer), then the maintenance requirements are more numerous.
  - Grease and oil moving equipment/parts.
  - Assess the condition of bearings, shafts, and motors.

Instrumentation

- The manufacturer's maintenance recommendations should be followed for all of the plant's instrumentation.
  - Instrumentation includes pressure gauges and flow meters.
- On-line analytical equipment includes chlorine analyzers, turbidimeters, particle counters and, perhaps, pH meters.
  - In order to have complete confidence in the on-line analytical equipment, it should be calibrated at least monthly by using the manufacturer's recommended procedures.
  - In-line sonic sensors are a direct method of testing for membrane integrity that does not require taking the entire membrane out of service.
- Most membrane systems will include some type of computer data logging system.
  - The results of the on-line analytical equipment will be downloaded directly to this system.
  - The operator should verify that this system is functioning properly, accurately recording data into the database, on a routine basis.

Equipment

- Like conventional facilities, membrane filtration plants contain pumps and valves; the maintenance requirements for these items are the same, regardless of where they are used.
  - The operator should refer to the manufacturer's recommendation to determine what maintenance activities and frequencies should be followed.
- Membrane treatment facilities utilize compressed air systems to operate hydro pneumatic valves, loss-of-head gauges, and other equipment, as well as using it as part of the RF and CIP processes.
  - If used for RF and CIP, the compressed air systems will be much larger than are typically found in a conventional treatment plant.
  - Regardless of the reason for use, compressed air systems are very important to the proper and efficient operation of a membrane plant.
  - Accordingly, the operator must conduct the manufacturer's recommended periodic maintenance procedures on the compressed air system.
- The membrane modules are sealed units and do not require any maintenance other than occasional cleaning and visual inspection for leaks or cracks.
- The racks contain pressure gauges and pressure differential sensors, as well as flow meters and associated equipment.
  - These items should be maintained according to manufacturer's recommendations.

Computer Control System

- The computer control system determines when RF and other routine functions are implemented.
- It also monitors the operation of all aspects of the system and alerts the operator via alarms when the operation is not satisfactory.
    - This capability is a great advantage and aids in the efficient operation of a membrane system.
- The operator should frequently verify that the data being displayed and recorded by the control system is accurate and indicative of system operation. This can be done in a number of ways.
    - Most on-line instrumentation has a local readout on the instrument itself; the operator, at a minimum, should verify that the local and computer readout agree.
    - Additionally, the operator should verify that the functions controlled by the computer---flux rate and RF frequency, flow, and duration—are being implemented according to the desired operational standards.
- The computer control system operates by maintaining operator entered set points.
    - The operator should regularly verify that the set points that were selected are still appropriate for the feed water quality and are being implemented by the control system.
- The control system is programmed to alert the operator when a certain set point is achieved.

What verification methods could you use to test the control system's set points?

Chemical Feed Systems

- Conduct daily checks on the chemical feed equipment to verify its proper operation.
- Note the amount of chemical used on a daily basis.
  - Significant changes in the daily amount of chemical usage could indicate a problem in the chemical feed system.
  - These systems should be maintained according to manufacturer's recommendations.

System Troubleshooting

There are a variety of systemic problems that an operator might face during routine operations at a membrane filtration facility. Three are listed below.

Rate of TMP Increase

Noticeable rate increases on TMPs can limit the amount of permeate produced and require frequent CIPs in order to maintain system productivity and efficiency.

What are some of the consequences of frequent CIPs?

The primary causes for rapidly increasing TMPs are changes in feed water quality or changes in the effectiveness of the pretreatment process.

- Conduct testing on feed water and pretreated water quality; then compare the results to historical water quality data.
  - Slight changes in feed water quality can have a significant impact on system operation.
  - At times, the feed water quality may change (although the change is not significant enough to require the implementation of a pretreatment process).
    - Many feed water quality changes are seasonal or meteorological in nature.
    - These transient changes in feed water quality typically are short lived and they do not require the implementation of a full scale pretreatment program.
    - They may be manageable by temporarily modifying the operating characteristics of the membrane filtration system.

- If the problem is a change in the feed water, then a pretreatment process will have to be established or, if already established, modified.

- If the problem is related to the effectiveness of the pretreatment process, then that process must be assessed and modified as necessary to produce a filterable feed water.

- Another possible solution for rapidly increasing TMPs is the modification of the frequency and duration (or the procedure used) to conduct system RF, or the flow path through the membrane.
  - By increasing the frequency or extending the duration of the RF, more material could be removed from the membrane's surface.
  - Removing more material may reduce the rate of TMP increase.

- Another possible modification involves adding or increasing the amount of air used during the RF process.

- Perhaps the most intriguing process modification is the relatively new technique we have referred to as maintenance chemical cleaning.
  - The goal of this cleaning is not to reduce TMP (as is the goal of a CIP), but to maintain the system's current TMP and extend the period between CIPs.
  - In the case of rapidly increasing TMP, a maintenance chemical cleaning could be conducted to stop the rapid increase in TMP.

Loss of Original Specific Flux

A membrane containing a large amount of material that is not easily removable is said to be fouled. Fouling is classified in one of two ways, reversible and irreversible.

- Reversible fouling can be removed, although it could require extraordinary efforts to dislodge the material.

- Irreversible fouling is fouling that cannot be removed from the membrane.

- In order to determine if a fouling is reversible, try to identify the material that is causing the fouling.
  - Different cleaning chemicals are effective on different types of fouling.
    - For instance, if the fouling is caused by metals, such as iron or manganese, an acidic cleaning chemical would be most effective at removing it.
    - Alternately, caustic type cleaning chemicals tend to more effective at removing organic fouling like algae.
      - Finding large numbers of algae in the feed water will tend to indicate that organic compounds may be causing the fouling.
      - Likewise, an increasing afternoon pH could indicate excessive algae activity in the source water.

- In practice, the nature of the fouling is usually only determined after the fact, by comparing the performance of the acidic and caustic chemicals.
  - If the acidic chemical is more effective at restoring the membrane's specific flux, then the fouling was predominately metallic.
  - Conversely, if the caustic chemical is more effective at restoring specific flux, then the fouling was predominately organic in nature.

If the fouling is truly irreversible, take steps to minimize its impact on the membranes. One goal of the pretreatment process should be to minimize irreversible fouling.

Finished Water Quality

- The finished water quality from a membrane treatment system should be very consistent in terms of turbidity, particle counts, and *Giardia* and *Cryptosporidium* levels.

- Changes in feed water quality may impact the operating characteristics of the system, but should not have any impact on the permeate quality.
  - If the permeate quality begins to deteriorate, the operator may suspect that the problem is related to a broken membrane fiber or fibers.
    - Although it would require a large number of compromised fibers, permeate turbidity, particle counts and Giardia and Cryptosporidium levels could become elevated if enough fibers are compromised.
    - On-line integrity testing will spot a broken fiber without the use of on-line turbidimeters or particle counters, but depending on the frequency of the integrity testing, it could be one or more days before the integrity test reveals the problem.

Operational Records

State regulations require that certain operational records be collected and maintained. Even if they were not required by the Pa. DEP, operational records can be an invaluable tool for the operator who is trying to diagnose operating problems.

Analytical Records

- Records of raw and finished water quality can be very useful reference materials for an operator.
- State regulations require that some records be maintained at the treatment plant. At a minimum, the operator should save the results of:
  - Raw and finished turbidity
  - Finished chlorine

Sampling Records

- Maintain a log of date, time, and location of samples taken for SDWA compliance.
  - The log can serve as verification that the samples were collected and submitted.
  - In addition, a record of samples taken to maintain operational control of the treatment can be useful.

System Operation Records

- An operator may need to know when an activity was last conducted.
  - For instance, CIP will most usually be conducted on a regular interval.
    - By consulting operational records, the operator can predict when the next CIP will be required.
    - If an operator suspects that the CIP frequency is increasing, a quick check of the records can verify it.
- System operation records should include:
  - Flux rate, actual and temperature corrected
  - TMP
  - Specific flux, actual and temperature corrected
  - Plant flow rates
  - Operational information on support equipment like air compressors, prefilters or strainers
  - Comments pertaining to the condition of the plant
  - Unusual events

Equipment Maintenance Records

Equipment Records

- Frequently, during maintenance or repair of equipment, a question of how to proceed will arise.
  - It is important to follow the manufacturer's recommendations for repair or maintenance of the equipment.
  - This information is almost always supplied by the manufacturer when the equipment is delivered.
  - Other sources of equipment information include:
    - Shop drawings
    - As-built drawings
    - Plant flow schematics

Maintenance Records

- There is no substitute for a good and conscientiously implemented maintenance program.
  - Even a good program will be of limited value without complete maintenance records.
  - Maintenance records need not be long or fancy, but they should include at a minimum:
    - The date maintenance was performed
    - The employee(s) who did the work
    - A description of the work that was done
    - A description of any unusual occurrences

Exercise

Unit 4 Exercise

True or False:

1. ______ In-line sensors are a direct method of testing membrane integrity that requires taking the membrane out of service for a short period of time.

2. _______ A possible change in feed water; a change in the effectiveness of pretreatment; and RF process parameters should be examined when determining the cause of a rapid increase in the membrane filtration system TMP.

3. _______ Reversible fouling can be removed, although it can be time and labor intensive to do so.

4. _______ Irreversible fouling is fouling that cannot be removed from the membrane surface. It usually results in the need to replace the membrane or to operate at a much higher flux rate than originally used.

5. _______ Permeate turbidity, particle counts, and Giardia and Cryptosporidium levels could become elevated if enough fibers are compromised. On-line integrity testing will spot a broken fiber without the use of on-line turbidimeters or particle counters.

Unit 4 Summary

Key Points:

- The normal operation of a membrane system is controlled by a computer control system. The operator should frequently verify that the data being displayed and recorded by the control system is accurate and indicative of system operation.
- Finished water quality can tell an operator a great deal about the health of the membrane treatment process. Common operational problems are a rapid buildup of TMP and loss of original specific flux (also known as fouling)
- Analytical records, sampling records, and system operation records should be collected and maintained.

Definitions:

Air scrub, or **AS,** is a process by which some membrane systems introduce air into the feed side of the filter module in conjunction with the RF process in order to enhance the RF's efficiency. The air agitates the surface of the membrane and enhances the removal of the material from the membrane's surface.

Back pulse is a smilar process of reversing the flow direction, but is used on submersible types of membrane filter systems.

Backwash recovery is a system in which the facility reclaims some or all of the RF waste from the system.
Membrane is a semi-permeable thin layer of material capable of separating contaminants as a function their physical/chemical characteristics.

Chemical Clean-in-Place (CIP) is a cleaning procedure that is used to restore the membrane's capacity to something near its original capacity.

Concentrate, or **reject,** is the waste created from an RF of a membrane system.

Cross flow means that a small portion of the feed water is allowed to flow across the surface of the membrane (rather than through the membrane).

Dead end flow means that all of the feed water entering the membrane is passing through the filter.

Feed water is the influent water for the membrane system; it is the water being added to the membrane system itself.

Flux is the flow rate through an individual membrane filter module expressed in terms of gallons of flow per square foot of membrane filter surface area per day.

Headloss is pressure drop. It is the difference between the pressure on the upstream side of the filter and the pressure on the downstream side of the filter.

Osmotic pressure is the pressure created by the difference in concentration of the constituents on either side of the membrane, and this pressure drives the osmosis process.

Permeate is the filtrate from a membrane filter. It is called permeate due to the way that the feed water permeates through the membrane.

Reverse flow is the process of reversing the direction of water flow through the filter using permeate (filtered water). The permeate removes the material deposited on the surface of the membrane and the waste stream is collected and removed from the module.

Reverse osmosis (RO) is the process of forcing water from the dirty side through the membrane into the clean water side, while leaving the undesirable constituents behind on the membrane itself.

Specific flux is the flux of the membrane divided by the TMP of the membrane itself. The lower the specific flux, the more pressure loss through the system and the more expensive it is to operate the system.

Temperature corrected flux is used to discuss flux in terms of a standard feed water temperature. The standard temperature for this is 20^oC (68^oF). This term is useful for comparing performance between different manufacturers' membranes. It is usually expressed as gfd @ 20^oC.

Temperature corrected specific flux for a membrane system is calculated by dividing a system's temperature corrected flux by the membranes' TMP.

Transmembrane pressure is the change in the pressure of the water as it passes through the membrane. Transmembrane pressure is referred to as TMP by most manufacturers.

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DEPARTMENT OF ENVIRONMENTAL PROTECTION FIELD OPERATIONS REGIONAL OFFICES:

REGION	ADDRESS
SOUTHEAST	PA DEP - SOUTHEAST FIELD OPERATIONS 2 EAST MAIN STREET NORRISTOWN, PA 19401 Phone: 484-250-5900
NORTHEAST	PA DEP - NORTHEAST FIELD OPERATIONS 2 PUBLIC SQUARE WILKES-BARRE, PA 18711-0790 Phone: 570-826-2511
SOUTHCENTRAL	PA DEP - SOUTHCENTRAL FIELD OPERATIONS 909 ELMERTON AVENUE HARRISBURG, PA 17110 Phone: 717-705-4704
NORTHCENTRAL	PA DEP - NORTHCENTRAL FIELD OPERATIONS SUITE 101 208 WEST THIRD STREET WILLIAMSPORT, PA 17701 Phone: 570-327-3675
SOUTHWEST	PA DEP - SOUTHWEST FIELD OPERATIONS 400 WATERFRONT DRIVE PITTSBURGH, PA 15222-4745 Phone: 412-442-4217
NORTHWEST	PA DEP - NORTHWEST FIELD OPERATIONS 230 CHESTNUT STREET MEADVILLE, PA 16335-3481 Phone: 814-332-6899