Drinking Water Operator Certification Training
Instructor Guide

Module 19:
Membrane Filtration

This course includes content developed by the Pennsylvania Department of Environmental Protection (Pa. DEP) in cooperation with the following contractors, subcontractors, or grantees:

The Pennsylvania State Association of Township Supervisors (PSATS)
Gannett Fleming, Inc.
Dering Consulting Group
Penn State Harrisburg Environmental Training Center

A Note to the Instructor

Dear Instructor:

The primary purpose of *Module 19: Membrane Filtration* is to introduce the topic of membrane filtration, become familiar with its operations, understand emerging issues surrounding the system, and to maintain the system. This module has been designed to be completed in 3 hours but the actual course length will depend upon content and/or delivery modifications and results of course dry runs performed by the DEP-approved sponsor. The number of contact hours of credit assigned to this course is based upon the contact hours approved under the DEP course approval process. To help you prepare a personal lesson plan, timeframes have been included in the instructor guide at the Unit level and at the Roman numeral level of the topical outline. You may need to adjust these timeframes as necessary to match course content and delivery modifications made by the sponsor. Please make sure that all teaching points are covered and that the course is delivered as approved by DEP.

Web site URLs and other references are subject to change, and it is the training sponsor's responsibility to keep such references up to date.

Delivery methods to be used for this course include:

- Lecture
- Exercises and In-class Activities

To present this module, you will need the following materials:

- One workbook per participant
- Extra pencils
- Laptop (loaded with PowerPoint) and an LCD projector **or** overheads of presentation and an overhead projector
- Screen
- Flip Chart
- Markers

Icons to become familiar with include:

Participant Workbook	Instructor Guide
Exercise/Activity	Same icons for Participant Workbook apply to the Instructor Guide.
Case Study	**Ans:** Answer to exercise, case study, discussion, question, etc.
Discussion Question	PowerPoint Slide
Calculation(s)	Overhead
Exercise	Flip Chart
Key Definition(s)	Suggested "Script"
Key Point(s)	

Instructor text that is meant to be general instructions for the instructor is designated by being written in script font and enclosed in brackets. For example:

[Ask participants if they have any questions on how to read the table. Answer any questions participants may have about how to read the table.]

If your module includes the use of a PowerPoint presentation, below are some helpful controls that you may use within the Slide Show.

PowerPoint Slide Show Controls

You can use the following shortcuts while running your slide show in full-screen mode.

To	**Press**
Advance to the next slide	N, ENTER, or the SPACEBAR (or click the mouse)
Return to the previous slide	P or BACKSPACE
Go to slide <number>	<number>+ENTER
Display a black screen, or return to the slide show from a black screen	B
Display a white screen, or return to the slide show from a white screen	W
Stop or restart an automatic slide show	S
End a slide show	ESC
Return to the first slide	Both mouse buttons for 2 seconds
Change the pointer to a pen	CTRL+P
Change the pen to a pointer	CTRL+A
Hide the pointer and button temporarily	CTRL+H
Hide the pointer and button always	CTRL+L
Display the shortcut menu	SHIFT+F10 (or right-click)
Erase on-screen annotations	E
Go to next hidden slide	H
Set new timings while rehearsing	T
Use original timings while rehearsing	O
Use mouse-click to advance while rehearsing	M

INTRODUCTION OF MODULE: <u>5 minutes</u>

Display Slide 1—Module 19: Membrane Filtration.

[Welcome participants to "Module 19– Membrane Filtration." Indicate the primary purpose of this course is to introduce the topic of membrane filtration, become familiar with its operations, understand emerging issues surrounding the system, and maintain the system.]

[Introduce yourself.]

[Provide a brief overview of the module.]

This module contains x units. On page i, you will see the topical outline for **Unit 1 – Overview of Membrane Filtration.**

[Briefly review outline.]

If you turn the page, you will see the topical outline for **Unit 2 – Membrane System Materials, Configurations, and Operations** and **Unit 3 – Regulatory and Economic Issues.**

[Continue to briefly review outline.]

Turn the page again to see the outline for **Unit 4 – Maintenance and Recordkeeping.**

[Finish the outline review.]

Now turn to page 1 for a list of the objectives to be covered in the first unit.

UNIT 1: <u>70 minutes</u>

Display Slide 2—Unit 1: Overview of Membrane Filtration.

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.

Display Slide 3—Unit 1: Overview of Membrane Filtration.

- Define the following terms:
  - Flux.
  - Temperature corrected flux.
  - Transmembrane pressure.
  - Specific flux.
  - Permeate.
- Explain the difference between cross flow and dead end flow in a membrane system.
- Identify and describe three different techniques that can be used to restore membrane flux or clean the membrane.

INTRODUCTION: 23 minutes

In this unit we will define what is meant by membrane filtration, compare it to conventional filtration, briefly describe the history of membrane filtration, mention regulatory issues, and describe the two basic system configurations. An overview of membrane technology, as well as definitions and terminology unique to membranes, will be presented.

[Review information in the workbook.]

Definition

There are many definitions that could be used to describe membranes. Your workbook contains a technical definition and a more common definition.

*[Review the definitions of **membrane**.]*

Comparison to Conventional Treatment

Conventional Filtration Design

[Review the first bullet point.]

Display Slide 4 – Conventional Filtration Removal Mechanisms.

This figure shows the three traditional methodologies for removal. You can see a representation of straining, in which particulate is caught between the filtering sands. In the center, adsorption is occurring, wherein particles are attracted and attached to particles of filter media. Finally, settling is represented. Here, the filter media slows the velocity of the particles as they travel through the filter bed. In some cases, the velocity is slowed enough for the particles to actually "settle" in the filter bed.

[Review the next bullet and its sub-bullet.]

Membrane Filtration Design

[Review information in the workbook.]

Display Slide 5 – Membrane Filtration Mechanism.

I am displaying a color version of Figure 1.2 from your workbook. As you can see, if the membrane is intact, then the removal of any material larger than the membrane's pore size will be 100%.

Comparison to Bag or Cartridge Filtration

Although there are similarities, there are two major differences between membrane filtration and bag or cartridge filtration. The most fundamental difference is the cleaning versus disposal difference.

[Review information in the workbook.]

History of Membrane Treatment

Before we begin to discuss the current uses and issues surrounding membrane filtration, it might be interesting to take a step back in time to review its history. The very first function of membrane filters, as a laboratory tool, is still in use today.

[Allow participants a few minutes to review the timeline.]

Membrane Filtration Uses in Water Treatment

Today, membrane filters have three basic functions. Each removes an unwanted particulate from drinking water supplies.

[Review information in the workbook.]

Regulatory Perspective

Membrane filters can be used to comply with a number of regulatory requirements.

[Review the information under the key topic.]

[Briefly review the remaining information in the workbook.]

System Configurations

[Review information in the workbook.]

Remember that membrane filtration may be the only treatment needed, but source water quality may demand further treatment. As we will learn in the next section, the exact type of pathogens, inorganic substances, and organic compounds must be considered when determining if membrane filtration alone provides adequate treatment.

[Review the key point.]

We will move on now to examine an overview of the membrane filtration process.

MEMBRANE TECHNOLOGY OVERVIEW: <u>25 minutes</u>

Membrane treatment processes are quite different from conventional water treatment. For this reason, there are a number of concepts that will be discussed in order to introduce you to the mechanisms and terminology used in a membrane filtration.

Principles of Membrane Filtration

You may recall Figure 1.2, where we noted that this technique is very valuable.

[Review the key point.]

[Review the definition of ***osmosis.]***

[Review the information in the workbook, and refer participants to Figure 1.3.]

You can see in this diagram that fresh water will travel through the membrane and dilute the dirty water.

[Review the key point.]

*[Review the definition of **osmotic pressure.]***

[Review information in the workbook and refer participants to Figure 1.4.]

You may be realizing, by looking at the diagram, that osmosis is not really desirable from the standpoint of treating water.

An operator's job is to make fresh water, and not to dilute dirty water with fresh water. So, what we need here is a way to make this process run backwards. We want to force water from the dirty side through the membrane into the clean water side and leave the undesirable constituents behind on the membrane itself, right?

This is where reverse osmosis comes into play. Reverse osmosis is the opposite—or reverse action—of osmosis.

[Review the definition of ***reverse osmosis.]***

Looking at Figure 1.5 in your workbook, you can see how the water is being forced one way—into the clean side—after passing through the filter. The clean water does not come back towards the influent and, due to the pressure being applied to the influent side of the membrane system, the clean water does not dilute the dirty water as would happen in osmosis.

Keep this diagram in mind as we move to the next topic.

[Review information in the workbook.]

These cleaning mechanisms have been developed and will be discussed in detail in later units of this module.

All types of membrane filtration utilize this concept of forcing flow through a membrane and depositing the unwanted constituents on the membrane itself to produce the filtrate.

Considerations for RO

In order to accomplish RO, the following steps are necessary.

[Review the two bullet points and their sub-bullets.]

Remember that osmotic pressure wants to make the system run in the opposite direction of the way we need it to run. So, a pump is usually used to create the pressure necessary to overcome the osmotic pressure in a membrane system.

As the filtration process proceeds, the undesirable constituents are carried to the membrane along with the water flow. Since the membrane has been selected to remove these constituents, they cannot pass through the membrane with the water and they build up on the surface of the membrane. This creates headloss through the system.

*[Review the definition of **headloss**.]*

The pump is used to overcome this headloss. Now you should have a better understanding of Figure 1.5, on page 10 of your workbook. Are there any questions?

Membrane Filter Applications

Due to the wide range of possible uses for membrane filtration, we will confine our discussion to drinking water production applications. You recall that we discussed the three basic uses: desalination; filtration of GUDI; and as a pretreatment process. Now we will concentrate on the applications of those uses.

[Review information in the workbook.]

Membrane Filtration Summary

Up to this point we have referred to different levels of membrane filtration as “tighter” or “looser” to indicate whether it had smaller or larger pore size. Of course there are more technical designations for these sizes.

[Review information in the workbook.]

[Refer participants to Table 1.1 on page 12.]

Table 1.1 compares the four membrane filtration levels by pore size range and by target contaminants. It is important to note that ranges overlap and, as a result, a filter with a level of 0.001 could be considered to be a reverse osmosis filter or a nanofilter.

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

Now let's look at the process through a graphical representation.

Display Slide 6 – Separation Chart.

The first row on the chart shows the pore size of the various filtration levels in microns. The second row presents pore size in terms of Molecular Weight Cut-Off (MWCO).

MWCO is actually the size of the molecule that will be retained on the membrane. For instance, a nanofilter will remove a molecule whose molecular weight is 20,000 Daltons (Daltons are a way to express molecular weight) but will allow a molecule whose molecular weight is100 Daltons to pass through. MWCO is usually only used when discussing RO or Nanofilters.

You will not need to calculate Daltons but you do need to understand how they are used to represent molecular weight.

Considerations for Selecting the Right Membrane Filter

[Review information in the workbook.]

TERMINOLOGY AND DEFINITIONS: <u>22 minutes</u>

Membrane filtration was first used outside of the realm of potable water treatment. For this reason, and others, some of the terminology used is quite different than is typically used in a water treatment plant. These terms, along with their equivalent terminology from traditional water treatment, will be presented in this section.

Flux

*[Review the definition of **flux** and its equivalent terminology.]*

[Review the key point.]

*[Review the definition of **temperature corrected flux**.]*

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; it is determined by the area of the membranes themselves. Each pressure vessel can contain hundreds of square feet of membrane surface area. These concepts will be discussed at length in Unit 2.

[Review the key point.]

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^{o}C.

[You may wish to show the answer on a flipchart.]

Ans: 5 gallons per minute x 60 minutes per hour x 24 hours per day = 7200 gallons per day.
7200 gallons per day / 75 sq. ft. = 96 gallons per square foot per day

Feed Water

*[Review the definition of **feed water**.]*

[Review information in the workbook.]

It is important to remember that feed water is the influent water to the membrane filters, but not necessarily the source water.

Transmembrane Pressure

*[Review the definition of **transmembrane pressure**.]*

As water passes through the pores of the filter, it loses some of its pressure. This is similar to headloss through other types of filters.

Specific Flux

*[Review the definition of **specific flux**.]*

*[Review the definition of **temperature corrected specific flux**.]*

[Review the key point.]

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.

Ans: This relates to the previous exercise's answer. We calculated the flux to be 96 gfd. In order to calculate specific flux, divide the flux by the TMP. 96 gfd / 20 psi. = 4.8 gfd/psi.

[Review the definition of ***permate.****]*

Cross Flow vs. Dead End Flow

These phrases describe two different operational modes for a membrane filter system.

[Review the definition of ***cross flow****.]*
[Review information in the workbook.]

[Review the definition of ***dead end flow****.]*

Reverse Flow and Back Pulse

When a rapid sand filter reaches its terminal headloss, it is backwashed to remove the particulate material from the filter. This reduces the headloss through the filter and restores it to a condition that will allow the filtration to proceed. Membrane filters also become clogged with particulate material, which creates a headloss through the filter.

[Review information in the workbook.]

[Review the definition of ***reverse flow****.]*

[Continue reviewing information under this topic.]

[Review the definition of ***back pulse****.]*

There is one other type of cleaning that is not very common.

[Review the information in the workbook.]

Frequency and Duration

[Review information in the workbook.]

Certainly, this RF frequency is quite different from conventional backwash frequencies and may seem to make membrane filtration hopelessly inefficient. It must be noted, however, that the duration of the RF cycle is extremely short, lasting usually only 30 seconds or so.

[*Review information in the workbook.]*

Volume

[Review information in the workbook.]

Percent Recovery

In a conventional treatment system it is typical to discuss the percent wash water used, but for membrane filtration we will talk about percent recovery.

[Review information in the workbook.]

What qualities determine the percent recovery in membrane treatment?

Ans: The three qualities are: membrane filtration level selected; the characteristics of the membrane itself; and the quality of the feed water.

Concentrate of Reject

Backwashing a rapid sand filter creates backwash wastewater.

[Review information in the workbook.]

Air Scrub

[Review information in the workbook.]

Backwash Recovery

Remember that membrane filter systems tend to be slightly less efficient in terms of percent recovery than conventional treatment plants.

[Review the definition of ***backwash recovery****.]*

[Review information in the workbook.]

Chemical Clean-in-Place

The RF and AS procedures are not as efficient as rapid sand filter backwash at restoring a filter's capacity. As the membrane filter ages, material that is not well removed by the RF and AS accumulates on the filter's surface. Eventually, a sufficient amount of this material will accumulate until the filter can no longer be operated efficiently.

*[Review the definition of **chemical clean-in-place (CIP)**.]*

[Review information in the workbook.]

New Methodology

A new technique is being used more regularly. It involves a chemical cleaning of the filter. The actual chemical(s) used and their strength, along with the actual cleaning procedure used during cleaning are manufacturer specific. Some manufacturers use sodium hypochlorite solely, or in conjunction with the caustic solution. Other manufacturers use solutions of surfactants for cleaning.

[Review information in the workbook.]

Now that we have covered all the information from Unit 1, you should know what membrane filtration is, how it came to be used, and why it is now used. You also know something about its benefits and limitations, and you have been introduced to many of the terms that are used in the field.

Exercise

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

Answer: 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

Answer: b. reverse osmosis

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

Answer: 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

Answer: b. – reverse flow

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

Answer: a. – permeate

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

Answer: a. – the desalination of salt water to produce potable water)

Now let us summarize Unit 1 with a few key points.

[Review the key points.]

UNIT 2: <u>75 minutes</u>

Display Slide 7—Unit 2: Membrane System Materials, Configurations, and Operation.

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.

Display Slide 8

- 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 CONSTRUCTION AND SYSTEM CONFIGURATIONS: 45 minutes

In this unit, we will describe the membrane system construction and systems configurations, and we will highlight some of the operational procedures that are used. In the first section of this unit, we will discuss the way membrane filter systems are constructed and configured. Also, characteristics and forms of the membrane itself will be described. We will touch briefly on the methods used for pretreatment of a system's feed water and will discuss some limitations of membrane filter systems.

Membrane System Components

Membrane treatment systems are modular in nature. The membrane system is comprised of the membrane itself, the modules that contain the membranes, and the racks on which the membranes are placed. Then, of course, there is piping required to carry the influent and effluent, and the FR, AS, and CIP chemicals.

Membranes

[Review information in the workbook.]

Notice Figure 2.1, a photograph of the individual membrane fiber. This membrane is an example of the hollow fiber membrane.

Modules

[Review information in the workbook.]

Figure 2.2 represents a membrane module.

Racks

[Review information in the workbook.]

Notice the photograph illustrating the rack configuration.

Piping Systems

The piping used in a membrane treatment system is not very different from a piping system in a conventional water treatment plant. There are a few exceptions, of course. One difference is the need for air piping to supply air for the AS process.

[Review information in the workbook.]

Chemical Tolerance

[Review information in the workbook.]

For example, Cellulose Acetate is not chlorine tolerant. If it is exposed to chlorine, it will begin to degrade and will eventually be destroyed. If filtration of a chlorinated feed water is desired, the water will have to be dechlorinated or another type of membrane—one that is chlorine tolerant—should be selected.

Forms of Membrane Filters

Up to this point, we have used what are known as hollow fiber membranes to illustrate some of the concepts of membrane filtration. Although hollow fiber membranes are one of the most widely used forms of membranes used in drinking water treatment, there are a number of other forms available. We will look at four.

Hollow Fiber

[Review information in the workbook.]

Note the drawing that represents a fiber. See the pores on the side and the open lumen at the top of the cylinder.

Spiral Wound

The configuration of a spiral wound filter is a bit difficult to picture. Imagine two pieces of paper, one lying on top of the other. The top sheet of paper is the membrane. Feed water flows on top of the membrane and permeates through it to the second sheet underneath. This sheet is impermeable; the water cannot pass through it. This is the permeate carrier and its function is to carry the permeate from the membrane out of the filter.

[Review information in the workbook. Note that the described arrangement is presented graphically in Figure 2.5]

Ceramic and Other Materials

Most of the various other materials from which membranes are constructed are specialized to specific applications and are not used extensively in water treatment.

[Review information in the workbook.]

Electrodialysis, or ED

Another relatively popular style of membrane treatment is ED. An ED membrane is similar to the other types of membranes that we have discussed because it operates by using a selective membrane to retain the materials for which removal is desired. There are differences, however. Let's look at those now.

[Review information in the workbook.]

Membrane System Configurations

There are two basic configurations for a membrane treatment system used for potable water treatment.

[Ask participants the following questions:]

In which system—pressure or vacuum—would the water be pushed through the membrane? In which system would the water be sucked through the membrane?

Ans: Pressure systems push the water through; vacuum systems suck the water through.

[Review information in the workbook.]

Flow Path

Flow paths through various types of membranes can be quite different from one another. The flow paths through different types of hollow fiber membranes and spiral wound membranes will be discussed in this section.

Hollow Fiber

Feed water can be introduced to the inside or outside of the fiber.

[Review information in the workbook. Be sure to indicate the importance of the key point.]

[Review the key point.]

Spiral Wound

The flow path through a spiral wound membrane is a bit more complicated to explain. As we mentioned earlier, a spiral wound membrane has envelopes of membrane sheets and permeate carriers. Some of the water permeates through the membrane and travels along the permeate carrier to the permeate tube. The remainder of the feed water stays off the feed side of the membrane and travels to the other end of the membrane module.

[Review information in the workbook.]

Pretreatment

Many feed waters contain substances that might cause fouling of the membrane surface or might cause the flux through the system to be so low that it would not be economically feasible to use membrane treatment.

[Review the key point.]

Establishing the Need for Pretreatment

Before selecting a type of pretreatment, the need for pretreatment must first be established. Historical records are valuable. They can reveal the levels of certain components of the feed water, indicate any seasonal changes that might be expected, and point out the duration of any sudden or seasonal changes in the feed water.

[Review information in the workbook.]

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 for a membrane filtration system?

Ans: Because a membrane filter would become clogged quickly if highly turbid water were added to the system, pretreatment to remove the large particulate matter would be prudent.

Methods of Pretreatment

Once the need has been established, we must look at the various methods available for pretreatment. Methods can be divided into four categories. The first category is filtration.

Filtration

Filtration of the feed water prior to membrane filtration is actually quite common. Small facilities use a bag or cartridge filter to prescreen the water before entering the membrane. The filters come in a variety of sizes, are relatively inexpensive to buy for a small facility, and are usually disposable. They protect the more expensive membrane filter from damage or fouling by large debris.

[Review information in the workbook.]

Clarification

Clarification can also be used as a pretreatment process prior to membrane filtration.

[Review information in the workbook. Note the importance of the key point.]

[Review the key point.]

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?

Ans: A raw water reservoir may encourage algae growth. This will degrade the quality of the water from a membrane filtration standpoint. While the turbidity lowers, algae present other problems.

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?

Ans: Yes; if there is any carryover of the polymer from the clarifier to the membranes, fouling of the filters could occur.

Chemical Treatment

The third pretreatment option is chemical. There are a number of possible chemical pretreatments that may be beneficial to a membrane filtration facility.

[Review information in the workbook.]

Oxidation Addition

Oxidant addition can be useful for a number of reasons. Let's review those.

[Review information in the workbook.]

Coagulant Addition

Coagulant addition can also be used in conjunction with membrane filtration, but the process can be tricky.

[Review information in the workbook.]

Powdered Activated Carbon (PAC) Addition

Another treatment chemical that can be used with membrane filtration is powdered activated carbon, or PAC.

[Review information in the workbook.]

System Limitations

Although membrane filtration is a very robust treatment technology, which is capable of removing many compounds from a feed water, there are some system limitations that must be considered. Such limitations include pressure, flux, and chemical tolerance.

Pressure

Any piece of equipment used in water treatment has a maximum pressure that it can withstand prior to damage.

[Review information in the workbook.]

Flux

All membrane filters have a maximum flux rate at which they can operate.

[Review information in the workbook.]

Chemical Tolerance

As we have discussed, not all membranes are tolerant of all the chemicals that may be found in water. Chlorine was mentioned; other organic chemicals and solvents may destroy some types of membranes.

OPERATIONAL PROCEDURES: 30 minutes

Automatic Procedures

There are four main procedures that a membrane filtration system is equipped to perform automatically.

[Review information in the workbook.]

Flux Maintenance

The first automatic procedure is flux maintenance.

[Review information in the workbook.]

Reverse Flow (RF)

As we learned earlier, the membranes in the filtration system will become clogged with the material that was removed from the feed water. If this material is not removed from the membrane, the system will be unable to produce the required amount of water.

[Review information in the workbook.]

After the RF procedure, frequency, and duration have been established, the system's computer will conduct the RF cycle without the need of operator involvement.

Maintenance Chemical Cleaning

The maintenance chemical cleaning procedure was described in Unit 1.

[Review information in the workbook.]

Cross Flow

Remember that cross flow is the process of allowing a small portion of the feed water to flow across the surface of the membrane, rather than flowing through the membrane.

[Review information in the workbook.]

Membrane Integrity

Since membranes are typically enclosed in some type of pressure vessel or process tank, it is impossible for the operator to visually inspect the fibers. A visual inspection of the filter is not particularly valuable, at any rate, since the membrane fibers themselves are relatively small, and any defects in them are not usually visible.

But, remember that membrane filtration is employed to remove undesirable material from the feed water. If the membrane is not intact, the removal process will be negatively impacted. So, the question on your mind might be, "How can an operator be sure that the membranes have not been damaged, are intact, and are producing a water that is free of the contaminants that the system is designed to remove?"

The answer is that the membrane system itself can be programmed to verify the integrity of the filters. Two categories of testing methods are direct and indirect methods.

Direct Method

There are a number of direct membrane integrity tests. One is used by most manufacturers; it is an air pressure test.

[Review the bulleted items in the workbook.]

Does anyone know how this could possibly work? How can a membrane that will pass water through it actually hold air pressure?

Ans: The molecules in air are actually significantly larger than a water molecule. The pore size of a membrane is large enough to allow water to pass through, but too small to allow the molecules in air to pass.

It is interesting to note that an air pressure hold test is extremely sensitive. The test can detect one broken membrane fiber in a module that may contain thousands of fibers.

[Finish reviewing information in the workbook.]

Indirect Methods

There are two primary indirect tests of membrane integrity.

[Review information in the workbook.]

Manual Procedures

Although membrane treatment systems are quite automated and capable of running unattended for long periods of time, there are a few procedures that must be conducted manually. We will look at two of the most common procedures.

Chemical Clean-in-Place (CIP)

[Review information in the workbook.]

CIP Initiation Criteria

[Review information in the workbook.]

One danger to using a time-based interval is that the feed water quality can change from season to season, and the time interval suitable for summer may not be suitable for winter.

Cleaning Solutions

There are a variety of cleaning solutions that are used on membranes. Membranes can be made from different materials, so the cleaning solution must be compatible with the membrane type.

[Review information in the workbook.]

Cleaning Methods

While a variety of methods are available, it is imperative to follow the manufacturer's guidelines.

[Review information in the workbook. Note the importance of the key point.]

[Review the key point.]

Why is the process labor intensive? Depending on the method and the chemicals used, the operator may have to mix the solutions from bulk liquids or dry chemicals. Depending upon the level of automation of the particular membrane system, the manual operation of certain hand valves and pumps may be required. Also, if extended soak or recirculation steps are used, CIP of a single rack could take three to four hours to complete.

Cleaning Efficiency

[Review information in the workbook. The calculation is for information purposes. Note the importance of the key point.]

[Review the key point.]

Neutralization and Disposal

After completing the cleaning procedure, there will be a significant amount of used cleaning solution. Let's look at some possible disposal methods and issues.

The first method is not really a disposal method at all. It is a way to minimize the amount of CIP waste that is generated during the cleaning process. Nearly all membrane facilities will have at least two racks; large facilities could have 10 to 20 racks full of modules.

[Review the recycling information in the workbook.]

After all of the racks have been cleaned, or after the CIP solution quality has deteriorated to the point where it cannot be reused, you must dispose of it. Neutralization may be the first step in the disposal process.

[Review information in the workbook.]

[Finish reviewing the neutralization/disposal information in the workbook.]

Membrane Repair

Recall our earlier discussion regarding a membrane system's ability to automatically conduct membrane integrity testing. The question that was not answered then is, "What exactly do you do when you find the broken membrane?" The short answer is: You try to repair the module.

Repairing the module consists of three steps. We will learn more about this process in this section. The first step, of course, is locating the compromised module.

Locating the Compromised Module

[Review information in the workbook.]

Finding the Broken Fiber(s)

Once you locate the module, the task of finding the specific broken fiber begins.

[Review information in the workbook.]

Repairing the Fiber

Now it is time to repair the broken fiber. The term, “repair,” is actually a bit misleading. The fiber is not really repaired; it is sealed.

[Review information in the workbook.]

There may be some concern that the “repaired” module has less filter area than before, so it may be less effective. However, the module contains thousands of fibers and the loss of just a few will not adversely effect the ability of the filter to produce sufficient amounts of permeate.

Membrane Replacement

Eventually, of course, the membrane modules will not be able to produce the required amount of water, and will need to be replaced. The replacement process is straightforward.

[Review information in the workbook.]

We have already talked about normal operational procedures; let's look at the startup and performance monitoring procedures in the next sections.

System Startup

The initial startup of a membrane system would be conducted by the system manufacturer, but it is important for operators to be as involved as possible in this operation. There are a number of systems that need to be thoroughly checked during a plant startup, including the compressed air and wastewater handling systems. Although they are quite important to the operation of a membrane facility, these items will not be addressed in this section due to time constraints and site-specific parameters.

[Review information in the workbook.]

Daily Process Monitoring

Membrane treatment systems require very little operator involvement during normal operations. The operator's primary responsibilities are to confirm that the control system is functioning properly and that the system is producing an acceptable water quality.

Let's discuss some specific daily monitoring tasks.

Flux

[Review information in the workbook. Ask for volunteers to answer the following question.]

Often, we mention that historical data and accurate records are important. Why should you collect, maintain, and refer to this information?

Ans: Various answers are possible; make sure participants mention, at a minimum, the following: looking for trends of increasing, decreasing, or unstable flux through the system; predicting CIP through TMP data; assuring finished water chlorination; monitoring turbidity and particulate counts.

TMP

System TMP is probably the most important parameter used to monitor system operation.

[Review information in the workbook.]

Turbidity

[Review information in the workbook.]

Particle Counts

[Review information in the workbook.]

Chlorine

[Review information in the workbook.]

Weekly Process Monitoring

[Review information in the workbook.]

In this unit we covered a wide terrain. We looked at the different forms of membrane and their flow paths; talked about pretreatment; discussed limitations that may preclude membrane filtration; and had an overview of monitoring tasks. In the next unit, we will examine the regulatory and economic issues that make membrane filtration a good fit—or a bad fit—for a particular water or facility.

[An exercise is on the next page. All answers can be found in their workbooks.]

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

Answer: a., c., d., and f.

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

Answer: b. - clarification

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

Answer: 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

Answer: b. chemical clean a membrane filtration system

5. Which of the following mechanisms are used by a membrane filter to remove particulate material from the water? (*Choose all that apply*)

   a. flux
   b. reverse flow
   c. particle counts
   d. chlorine
   e. cross flow
   f. TMP
   g. turbidity

Answer: a., c., d., f., g.

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

Answer: c. 0.2 mg/L, 4 hours

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

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

Now let us summarize Unit 2 with a few key points.

[Review the key points.]

This page contains references used in this unit.

UNIT 3: <u>15 minutes</u>

Display Slide 9—Unit 3: Regulatory and Economic Issues.

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.

Display Slide 10

- 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 wash water.

REGULATORY ISSUES: <u>8 minutes</u>

In this unit, regulatory and economic issues relating to membrane treatment will be presented. In the regulatory issues section, we will examine the different levels of membrane treatment and how they may be employed to comply with various PA DEP regulations. In the economic section, we will discuss the factors that need to be considered when calculating the costs of operating a membrane treatment system.

Surface Water Treatment Rules

[Review information in the workbook.]

Disinfection Byproducts

[Ask participants to answer aloud the following question.]

How might disinfection byproducts be formed in the membrane filtration process?

Ans: They are formed, primarily, through the reaction of organic precursors with chlorine.

[Review information in the workbook.]

Microfilters and Ultrafilters

[Ask participants to recall earlier information and answer the following question.]

Do microfilters and ultrafilters remove soluble material from the water?

Ans: No; they remove only particulate material.

[Review information in the workbook.]

Suppose a treatment facility was using relatively large amounts of chlorine in order to achieve the required CT values and to satisfy chlorine demands of the water. Because the filters have a high success rate at Giardia and Crypto removal, less chlorine would be needed for that purpose. Therefore, reducing the amount of chlorine used would reduce the amount of DBPs produced.

Nanofiltration and Reverse Osmosis

[Review information in the workbook.]

Radon

[Review information in the workbook.]

Arsenic

[Review information in the workbook.]

Filter Backwash Rule

[Review information in the workbook.]

ECONOMIC ISSUES: 7 minutes

The costs of operating this type of facility are determined by several factors. One thing to consider: labor costs for a membrane facility may be somewhat less than for a similarly sized conventional treatment plant because of the typically automatic operation of this system. Let's look briefly at the other considerations.

Flux Rate

A significant factor in determining the costs of installing and operating a membrane filtration system is the flux rate at which the membranes can be operated.

[Review information in the workbook.]

TMP

Another factor is the pressure that the pumps must overcome in order to deliver water to the distribution system, also known as TMP. Of course, every water plant has a system head pressure that it must overcome (except a purely gravity fed system), but a membrane system must also overcome the pressure drop through the filters themselves.

[Review information in the workbook.]

Membrane Replacement Frequency

The frequency and cost of replacing membrane modules must be considered. As we discussed earlier, the material that is deposited on the membrane impedes the water flow and causes the TMP to increase.

[Review information in the workbook.]

This was a brief overview of the regulatory and economic issues surrounding the treatment process. You will probably not be called on to make these kinds of decisions, but knowing the factors that encourage or discourage membrane filtration will help you to understand the importance of our next unit, which deals with maintenance and documentation functions.

[An exercise appears on the next page. If time permits, allow participants to complete the exercise. If not, encourage them to use it as a valuable study/refresher tool. All the answers can be found in the workbook.]

Exercise

Unit 3 – Exercise

Fill in the blank:

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

Answer: turbidity

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

Answer: 99.9

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

Answer: PAC and chlorine.

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.

Answer: Nanofiltration and RO

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

Answer: flux and TMP

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.

Answer: ion and buffering

Now let us summarize Unit 3 with a few key points.

[Review the key points.]

UNIT 4: <u>20 minutes</u>

Display Slide 11—Unit 4: Maintenance and Recordkeeping.

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.

Display Slide 12

- 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.

SYSTEM MAINTENANCE: 12 minutes

In this unit, we will spend a few minutes with the general maintenance requirements and recordkeeping tasks associated with membrane filtration systems. Maintenance activities are straightforward and consist of verifying and maintaining common water treatment equipment like pumps, motors, valves, and analytical equipment. The recordkeeping section will detail the records that should be collected and maintained at the facility.

Prefilter

Maintenance requirements for the prefilter system depend upon the type of prefilter that is used.

[Review information in the workbook.]

Instrumentation

The maintenance requirements for on-line analytical equipment or plant instrumentation are relatively modest in a membrane filtration plant.

[Review information in the workbook.]

Equipment

Equipment maintenance requirements for a membrane filtration facility are, by and large, the same as the equipment maintenance requirements for a conventional treatment facility. The two pieces of equipment that will not be found in a conventional treatment plant are the membrane modules and the racks.

[Review information in the workbook.]

Computer Control System

The normal operation of a membrane filter system is controlled by a computer system. This capability is a great advantage and aids in the efficient operation of the membrane system. However, an operator may become somewhat complacent and assume that the computer will perform flawlessly all the time. This could be a dangerous assumption.

Assume for a minute that you, as an operator, determine that the most effective RF frequency is once every thirty minutes. You can program the system to operate under those conditions. However, you will still need to monitor the outcomes, and verify that the computer is doing what you told it to do.

[Review information in the workbook.]

The last point was perhaps the most important. System verification of alarms is mandatory.

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

Ans: Here is one example: Perhaps the system is programmed to alarm if the permeate turbidity from a rack of modules exceeds 0.2 NTU. It is likely that the turbidity of a membrane system will never approach this level, but it is important to verify that the system would alarm if the system did reach the level. In order to verify this, the operator can reset the alarm set point in the computer to an extremely low level, such as 0.01 NTU and wait to see if the system sounds an alarm.

Another method would involve causing the turbidimeter readout to exceed that 0.2 NTU setting by obscuring the light source in the turbidimeter itself. If this method is used, the operator should be sure to log the reason for the turbidity excursion from the membrane rack in case the reading is called into question at a later date.

Chemical Feed Systems

Maintenance activities of the chemical feed systems are the same in any type of water treatment facility.

[Review information in the workbook.]

System Troubleshooting

In this section, we will discuss some of the common irregularities of operations and their possible causes. Due to the unique nature of different manufacturers' membrane systems, the causes and possible solutions may not be applicable to every type of membrane filtration system. The first line of defense—and the most important minimum maintenance guideline—is to read and follow the manufacturer's recommendations for your specific equipment.

Rate of TMP Increase

Perhaps the most common operational problem is an abnormally rapid buildup of TMP.

[Review up to the discussion question in the workbook.]

What are some of the consequences of frequent CIPs?

Ans: CIPs are labor intensive; the rack undergoing the CIP is not available to produce permeate; the rack that is out of service can cause the other rack(s) to operate at a slightly higher flux rate, in turn causing the TMPs of those racks to increase. Also, frequent CIPs can shorten the lifespan of the membranes themselves.

In order to fix the TMP problem, we first have to identify the cause. Then we can identify a method to correct the problem.

[Review information in the workbook.]

[Finish reviewing the TMP section on this page of the workbook.]

Do you remember that, in Unit 1, you were introduced to the maintenance chemical cleaning process? This was the technique that involved using cleaning chemicals and soaking and/or circulating this solution around the membranes.

Loss of Original Specific Flux

Think back now to Unit 2, where you learned that the loss of original specific flux is a measure of how successful the CIP is at returning the membrane to its original condition. The faster the membrane loses its original specific flux, the faster it will need replacing. The loss is generally related to the inability of the CIP process to remove some of the material from the membrane's surface.

[Review information in the workbook.]

[Finish reviewing the section on loss of original flux. Note the importance of the key point.]

We have presented this information, in part, because it helps to illustrate the importance of an operator's experience even in this system that operates nearly automatically. If an operator has experienced past fouling episodes that have been caused by algae, he or she will be more likely to attempt a caustic based cleaning solution first. These "best guesses" based on experience can potentially reduce the amount of system downtime and waste that is generated, while at the same time maximizing production.

[Review the key point.]

Finished Water Quality

Our last example system troubleshooting reminds us that the finished water quality has a story to tell. Its consistency or its problems are a result of the process that created it. We can learn a great deal about the health of the process by examining the health of the finished product.

[Review information in the workbook.]

RECORDKEEPING: <u>8 minutes</u>

Operational Records

Operational records for a membrane filtration facility fall into three main categories: analytical records; sampling records; and system operation records.

Analytical Records

Referring to past operational practices often reveals the solution to a current problem.

[Review information in the workbook.]

Sampling Records

The facility is required to take specific samples to maintain compliance.

[Review information in the workbook.]

System Operation Records

[Review information in the workbook.]

Equipment Maintenance Records

During the course of normal plant operations, questions will always arise about the nature of a specific piece of equipment, what maintenance procedures to follow, or the results of a previous maintenance activity. No one's memory is infallible; good records are imperative.

Equipment Records

[Review information in the workbook.]

Maintenance Records

[Review information in the workbook.]

We have now completed the fourth, and final, unit of Module 19. We used very broad and general topics to address the issue of maintaining a system and its records. Remember that your equipment probably is different from the neighboring town's equipment. Always consult your manufacturer's instructions.

Exercise

Unit 4 Exercise

True or False:

1. ____**F**__ 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.
   (False because, in-line sensors do not require taking the entire membrane out of service.)

2. ____**T**___ 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. ____**T**___ Reversible fouling can be removed, although it can be time and labor intensive to do so.

4. ____**F**___ 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.
   (False because, operate at a lower flux.)

5. ____**T**___ 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.

Now let us summarize Unit 4 with a few key points.

[Review the key points.]

That concludes Unit 4 and Module 19 – Membrane Filtration. Are there any final questions?

[Answer question and dismiss.]