

Membrane Filtration Processes for Wastewater Treatment

Microfiltration (MF), Ultrafiltration (UF), and Membrane Bioreactors (MBRs)

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1. INTRODUCTION

Water treatment by membrane processes covers a wide field of technologies related to the treatment of municipal, agricultural and industrial wastewater, water purification, desalination, water recovery from wetlands, and remediation of contaminated soil. It are modern physicochemical separation techniques that use differences in permeability (of water constituents) as a separation mechanism. During membrane treatment, water is pumped against the surface of a membrane, resulting in the production of product and waste streams, as shown on [Figure 1](#). The membrane, typically a synthetic material less than 1 mm thick, is *semipermeable*—meaning that it is highly permeable to some components in the feed stream and less permeable (or impermeable) to others. During operation, permeable components pass through the membrane and impermeable components are retained on the feed side. As a result, the product stream is relatively free of impermeable constituents and the waste stream is concentrated in impermeable constituents.

In all cases the motivation to treat wastewater is given by the concurrent scarcity of freshwater and the increasing demand for it by a growing world population. Furthermore, the increase in human population has cascading effects on water availability and treatment with agriculture and industrial use polluting groundwater and high population concentration in cities producing ever-larger volumes of waste to treat. In all these instances, membranes play a key role in controlling the composition of the treated water stream, via the removal of toxic substances and the recovery of water for reuse. This can be attributed to the ability of membranes, with the appropriate pore or MWCO size, to provide an effective barrier to any contaminants present in the water to treat. As

the size of these contaminants, from ions to bacteria, varies several orders of magnitude, water treatment plants often contain several membrane processes in series with decreasing MWCO.

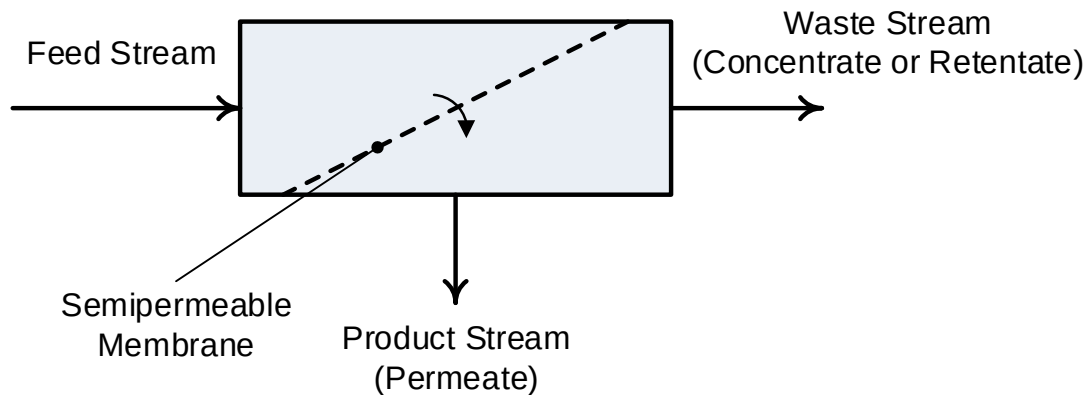


Figure 1

Schematic of separation process through semipermeable membrane.

2. CLASSIFICATION OF MEMBRANE PROCESSES

Four types of pressure-driven membranes are currently used in wastewater treatment: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) membranes. The hierarchy of membrane processes is shown on [Figure 2](#). The distinction between the types of membranes is somewhat arbitrary and subject to differing interpretations, but the membranes are loosely identified by the types of materials rejected, operating pressures, and nominal pore dimensions (which are identified on an order-of-magnitude basis on [Figure 2](#)). A “*loose*” NF membrane marketed by one manufacturer might be substantially similar to a “*tight*” UF membrane marketed by another manufacturer. As used in water treatment, these membranes can be classified into two distinct physicochemical processes: (1) membrane filtration and (2) reverse osmosis.

Microfiltration (MF) and ultrafiltration (UF) membranes are mainly employed to remove solid particles and microbes/bacteria. These are often used as a pretreatment step for nanofiltration (NF) and reverse osmosis (RO) membrane processes that can remove natural organic matter (NOM), viruses, and ions. Each stage is complemented by a host of other treatment processes (e.g., mesh screening, coagulation, UV disinfection, ozonation, etc.). An example of an integrated membrane process is represented by membrane bioreactors (MBRs), where a biological treatment process to degrade suspended organic matter is coupled with a membrane filtration system to retain the biomass, producing a clarified and disinfected effluent.

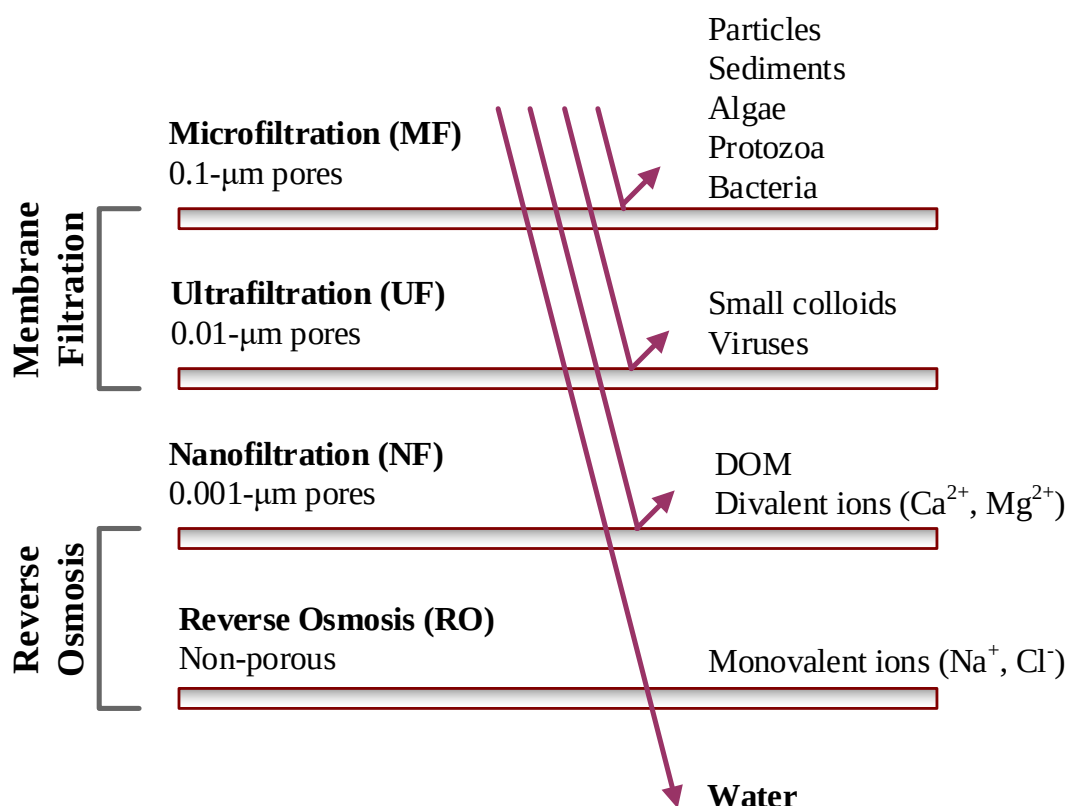


Figure 2

Hierarchy of pressure-driven membrane processes.

MBRs are rapidly supplanting legacy activated sludge treatment plants for municipal wastewater due to a smaller footprint, reduced use of chemicals, and superior quality of the treated water. Current MBR plants employ UF membranes with NF ones

being currently assessed as they can also remove viruses and some organic molecules, reducing the need for further treatment downstream. Membrane fouling remains the main obstacle toward more widespread adoption of MBRs as it requires expensive gassing and chemical cleansing to avoid dramatic flux reductions caused by the formation of biofilms on the membrane feed side. That is why all efforts are focused on reducing fouling rates through the development of pretreatment technologies.

Nanofiltration (NF) membranes in water treatment are mainly used for softening hard water (remove calcium and magnesium ions), freshen brackish waters, and reduce the concentration of NOM to control disinfection by-product (DBP) formation. Typically, thin film composite (TFC) semipermeable membranes are used, though the high pressures required somewhat limit their use (permeate recovery hasn't exceeded 70%, at all events). NF membranes are also effective at reducing viruses and pesticides, which of particular importance for the treatment of agricultural waste.

In reverse osmosis (RO) membrane systems, the feed stream is a solution, or single-phase system, in which the constituents targeted for removal are truly dissolved solutes (ions such as sodium, chloride, calcium, or magnesium, and dissolved NOM). The primary goal of reverse osmosis is to reduce the concentration of these solutes in the product water. Thus, RO membranes often represent the so-called polishing step in water treatment. Also, RO membranes are used to produce potable water from ocean or brackish water and to remove specific dissolved contaminants (e.g., pesticides, arsenic, nitrate, radionuclides), at the cost of significant energy expenditure to force the saltwater through the membrane. (Rejection of boron by RO membranes remains low under typical operating conditions.) Furthermore, RO membranes require extensive pretreatment steps to remove solids, particulate, and organic matter. Some RO membranes also require dechlorination of the feed to prevent swelling of the membrane selective layer with consequent loss of ion rejection.

3. DIFFERENCES BETWEEN MEMBRANE PROCESSES

Although membrane filtration (MF & UF) and reverse osmosis (NF & RO) are both pressure driven membrane processes; however, there is a substantial difference between

them. The predominant removal mechanism in membrane filtration is straining, or size exclusion, so the process can theoretically achieve perfect exclusion of particles regardless of operational parameters such as influent concentration and pressure. Mass transfer in reverse osmosis, however, involves a diffusive mechanism so that separation efficiency is dependent on influent solute concentration, pressure, and water flux rate. Differences between membrane filtration and reverse osmosis are evident in the materials used for the membranes, the configuration of the membrane elements, the equipment used, the flow regimes, and the operating modes and procedures. Additional comparisons between membrane filtration and reverse osmosis are detailed in [Table 1](#). It should be noted that membranes are used for many purposes in a wide variety of fields and industries, and the distinction between membrane types as used in water treatment may not be appropriate in other industries. Often, UF membrane use in those applications involves phenomena (such as concentration polarization, CP).

Table 1

Comparison between membrane filtration and reverse osmosis

Process Characteristic	Membrane Filtration	Reverse Osmosis
Objectives	Particle removal, microorganism removal	Seawater & brackish water desalination, softening, NOM removal, specific contaminant removal
Target contaminants	Particles	Dissolved solutes
Membranes types	MF, UF	NF, RO
Typical source water	Fresh surface water (TDS < 1000 mg/L)	Seawater, brackish water, groundwater (TDS = 1000–20,000 mg/L)
Membrane structure	Homogeneous or asymmetric	Asymmetric or TFC

Table 2 (Cont.)

Most common membrane configuration	Hollow fiber	Spiral wound
Dominant exclusion mechanism	Straining	Differences in solubility or diffusivity
Removal efficiency of targeted impurities	Frequently 99.9999% or greater	Typically 50–99%, depending on objectives
Most common flow pattern	Dead end	Tangential
Operation includes backwash cycle	Yes	No
Influenced by osmotic pressure	No	Yes
Influenced by CP	No	Yes
Noteworthy regulatory issues	Challenge testing and integrity monitoring	Concentrate disposal
Typical transmembrane pressure	0.2–1 bar (3–15 psi)	5–85 bar (73–1200 psi)
Typical permeate flux	30–170 L/m ² .h (18–100 gal/ft ² .d)	1–50 L/m ² .h (0.6–30 gal/ft ² .d)
Typical water recovery	>95%	50% (for seawater) to 90% (for colored groundwater)
Competing processes	Granular filtration	Carbon adsorption, ion exchange, chemical softening, distillation

4. MEMBRANE FILTRATION EQUIPMENT AND OPERATION

Membrane filtration occurs when water is forced through a thin wall of porous material. The filter medium is not woven or fibrous like cloth but is a continuous mass with

tortuous interconnecting voids. Nearly all membrane filtration systems installed use polymeric membranes. Polymeric membranes are almost always configured as hollow fibers. The fibers have an outside diameter ranging from about 0.65 to 2 mm and a wall thickness (i.e., membrane thickness) ranging from about 0.1 to 0.6 mm. Although the hollow fiber configuration is the most common used in water treatment, other configurations exist and are in widespread use in other industries.

The water passing through the membrane is called permeate, and water remaining on the feed side is called retentate. As solids accumulate against the filter medium, the head across the membrane required to maintain constant flux increases. The difference in pressure between the feed and permeate is known as the *transmembrane pressure* (TMP). The TMP is between 0.2 and 1 bar (3 and 15 psi) for most membrane filtration systems. Keeping pressure below 1 bar (15 psi) helps minimize membrane fouling.

Membrane filters operate over a cycle consisting of two stages, just like granular filters: (1) a filtration stage, during which particles accumulate, and (2) a backwash stage, during which the accumulated material is flushed from the system. During the backwash cycle, air and/or water is used to remove accumulated solids. Typical permeate flux, operating pressure, and duration of filter and backwash cycles, along with a comparison to rapid granular filtration, are presented in [Table 2](#). Although the backwash removes accumulated solids, a gradual but continuous loss of performance is observed over a period of days or weeks, as shown on [Figure 3](#). The loss of performance, or fouling, is due to slow adsorption or clogging of material that cannot be removed during backwash. Fouling affects the cost effectiveness of membrane filtration. Fouling is minimized by periodically adding chemicals to the backwash cycle, known as chemically enhanced backwash (CEB), and periodic chemical cleaning, known as the clean-in-place (CIP) cycle. CIP typically involves soaking the membranes for several hours in one or more warm solutions containing surfactants, acids, or bases. The cleaning frequency may range from a few days to several months, depending on the membrane material, operating conditions, and raw-water quality. The membranes degrade over a longer period of time, and replacement may be necessary after a period of 5 to 10 years.

5. MEMBRANE FILTRATION MODULE CONFIGURATIONS

As shown in [Table 2](#), the flux through a membrane filter is typically about two orders of magnitude lower than the flux through a rapid granular filter; consequently, a membrane filtration plant needs 100 times the filter area of a rapid granular filtration plant to produce the same quantity of water. One characteristic of membrane filtration plants, however, is that they are frequently more compact than granular filtration plants. This apparent contradiction is possible because membrane plants are constructed by packing thousands of hollow fibers into modules; thus, 1 m² of floor space at a membrane plant may contain more than 100 m² of membrane area. Membrane modules are available in two basic configurations:

- Pressure-Vessel Systems or
- Submerged Systems.

In both cases, MF or UF membranes with pore sizes from 0.01 to 0.1 μ are used in a hollow-fiber format. Polyvinylidene fluoride membranes often are specified to provide durability and chemical compatibility.

Table 2

Operating characteristics of membrane and rapid granular filters

Property	Membrane Filtration	Rapid Granular Filtration
Filtration rate (permeate flux)	0.03–0.17 m/h	5–15
Operating pressure	0.2–1.0 bar	0.18–0.3
Filtration cycle duration	30–90 min	1–4 d
Backwash cycle duration	1–3 min	10–15 min
Ripening period	None	15–120 min
Recovery	>95 %	>95 %
Filtration mechanism	Straining	Depth filtration

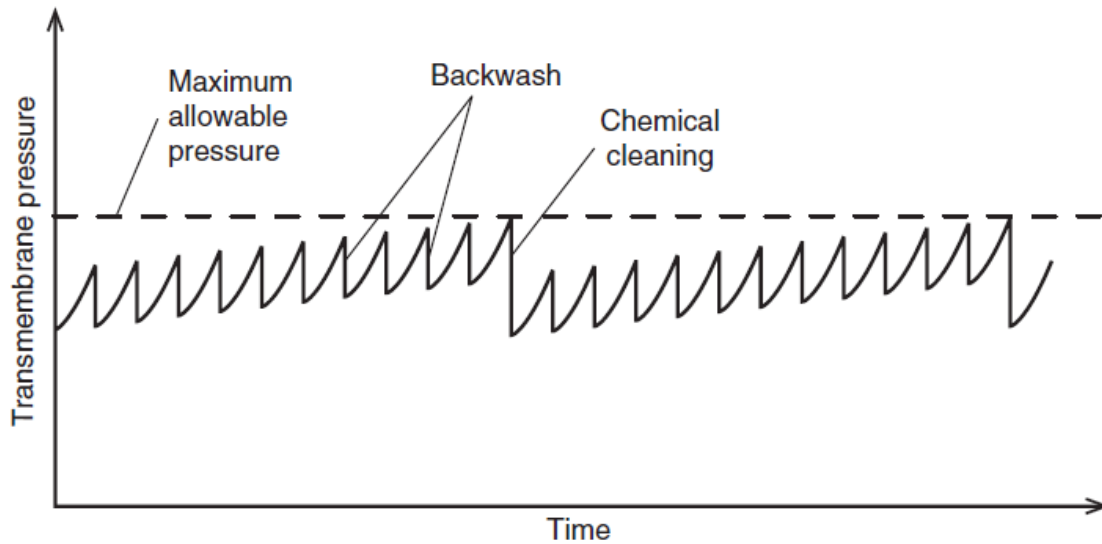


Figure 3

Transmembrane pressure development during membrane filtration.

5.1. Pressure-Vessel Membrane Filtration Modules

In a pressure system, membranes are mounted in a housing and feedwater is forced through pores with a feed pump. The modules are generally 100 to 300 mm (4 to 12 in.) in diameter, 0.9 to 5.5 m (3 to 18 ft.) long, and arranged in racks or skids. Typical pressure-vessel membrane elements are shown on [Figure 4](#). A single module has thousands of fibers and typically contains between 40 and 80 m² (430 and 860 ft²) of filter area. The rack or skid is the basic production unit, and all modules within one rack are operated in parallel simultaneously. Racks can contain between 2 and 100 modules, depending on capacity requirements. Feed high pressure pumps typically deliver water to a common manifold that supplies each rack. Each module must be piped individually for feed and permeate water, so large racks involve a substantial number of piping connections. Transmembrane pressure is developed by a feed pump that increases the feed water pressure, while the permeate stays at near-atmospheric pressure. Pressure-vessel systems typically operate at transmembrane pressures between about 0.4 and 1 bar (6 and 15 psi).

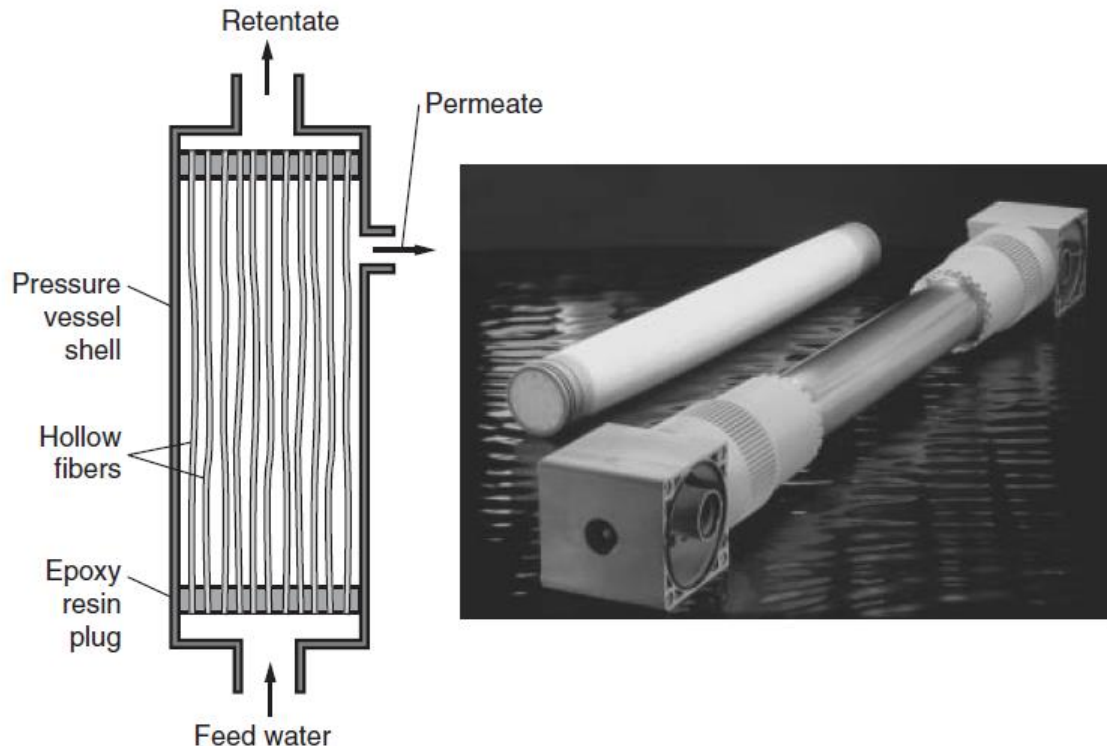


Figure 4

Pressure-vessel configuration for membrane filtration: (a) schematic of a single cross-flow membrane module and (b) photograph (*courtesy of US Filter Memcor Products*).

5.2. Submerged Membrane Filtration Systems

In Submerged systems (or immersed membranes), the modules of membranes are immersed in basins or open tanks containing feed water, as shown on [Figure 5](#). Because the basins are open to the atmosphere, so pressure on the influent side is limited to the static pressure provided by the water column. Transmembrane pressure is developed by a vacuum pump that develops suction on the permeate side of the membranes; thus submerged systems are sometimes called suction- or vacuum-based systems. Net positive suction head (NPSH) limitations on the permeate pump restrict submerged membranes to a maximum TMP of about 0.5 bar (7.4 psi), and they typically operate at a TMP of 0.2 to 0.4 bar (3 to 6 psi). Submerged systems are configured with multiple basins so that individual basins can be isolated for cleaning or maintenance

without shutting down the entire plant. Each basin typically has its own vacuum permeate pump.

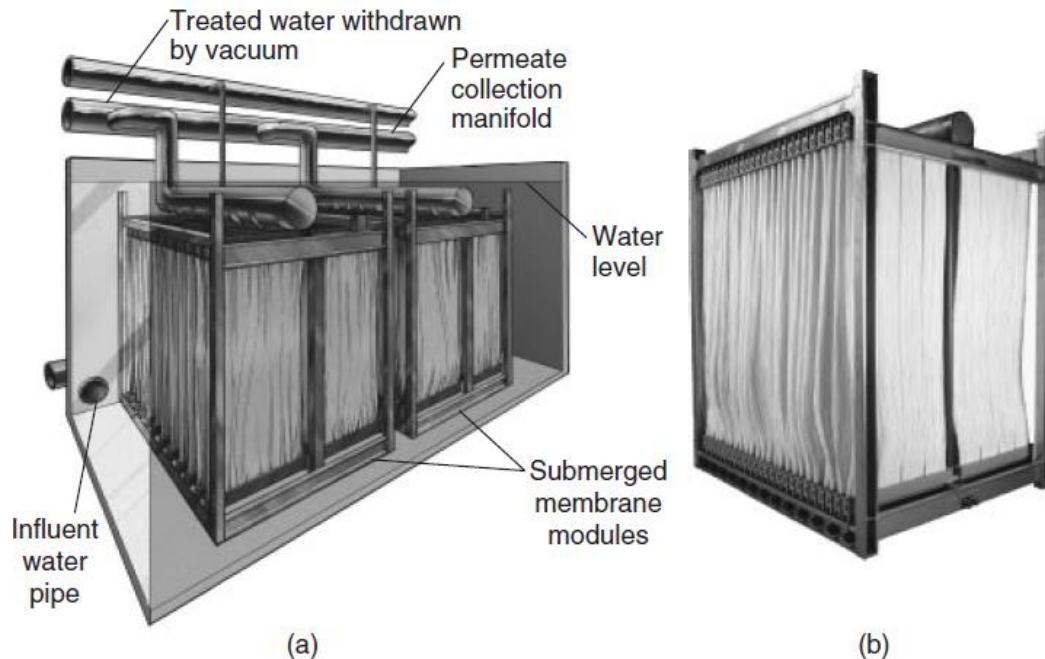


Figure 5

Submerged configurations for membrane filtration: (a) schematic of a submerged membrane module and (b) photograph of a single module.

For typical submerged membranes, the wastewater flows from the outside of the membrane tube to the inside. A vacuum is used to draw the water through the membrane to the inside of the tube and then to the treated water discharge. Treated water from a membrane is called permeate. A suction is placed on the inside of the membrane tube causing the water to permeate through the pore from the outside of the tube to the inside of the tube.

Because clean water is extracted from the feed basin through the membranes and solids are returned directly to the feed tank during the backwash cycle, the solids concentration in the feed tank can be significantly higher than in the raw water. A high solids concentration can be advantageous when using treatment additives (i.e., coagulants or PAC) to remove dissolved contaminants but can have an adverse impact

on the solids loading on the membrane during filtration. Two basic strategies are used to maintain the proper solids concentration in the feed tank, as shown on [Figure 6](#):

- (1) The feed-and-bleed strategy and
- (2) The semibatch strategy.

In the feed-and-bleed strategy, a small waste stream is continuously drawn from the feed tank (see [Figure 6a](#)) and the average solids concentration in the tank will be a function of the size of the waste stream.

The semibatch strategy operates without a continuous waste stream, and the feed and permeate flows are at the same rate. As a result, solids accumulate in the feed tank during the filtration cycle. During the backwash cycle, the volume of water in the tank increases due to addition of the backwash flow (raw water continues to flow to the tank during the backwash cycle), and the excess water (and solids) exits the basin through an overflow trough or port (see [Figure 6b](#)).

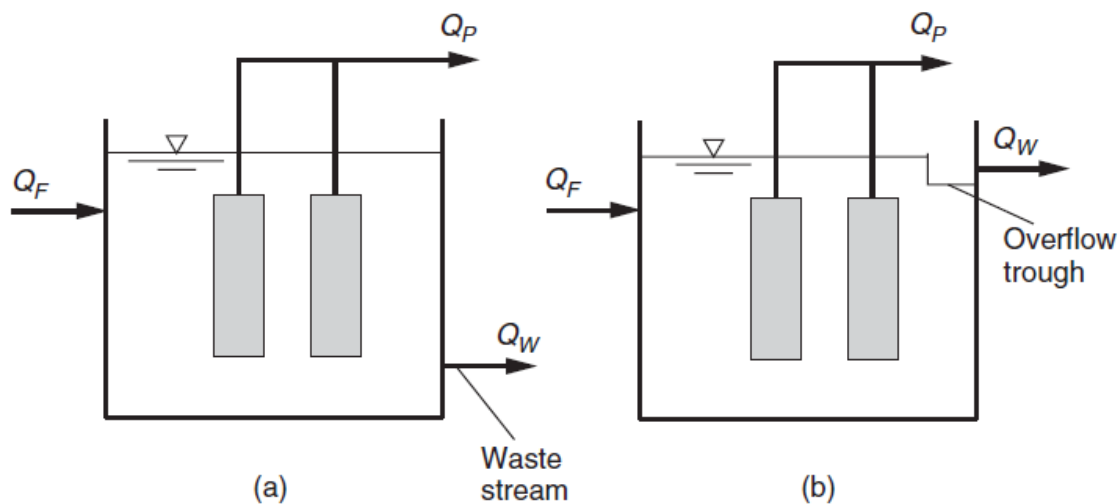


Figure 6

(a) Feed-and-bleed and (b) semibatch modes of operation. In feed-and-bleed, Q_P and Q_W are both continuous, the sum of the two flows equals Q_F . In semibatch, Q_P is continuous and equal to Q_F , Q_W only flows when solids are being wasted.

The use of submerged hollow fiber membranes can be classified into three main application areas, namely, surface-water treatment for drinking purposes, pretreatment

for RO desalination and reclamation, and membrane bioreactors (MBRs). The former two usually are operated in the dead-end filtration mode with intermittent backwashing, while the third is usually operated as a continuous filtration process with bubbling for inducing tangential shear to mitigate fouling. [Table 3](#) summarizes the submerged membrane-filtration applications and benefits.

Table 3

Submerged membrane-filtration applications and benefits.

Application	Operation Mode	Intermittent Fouling Control	Is Bubbling Implemented?	Advantages
Surface-water treatment	Dead-end with Intermittent foulant removal	Backwashing, relaxation, chemical cleaning	With or without bubbling during foulant removal	Less chemical requirements; Consistent quality of the filtrate
Pretreatment of RO	Dead-end with Intermittent foulant removal	Backwashing, relaxation, chemical cleaning	With or without bubbling during foulant removal	Improved water quality; smaller footprint; less chemical requirements; consistent quality of the filtrate; lowered energy cost for RO plants
Membrane Bioreactors (MBRs)	Cross-flow with tangential shear	Continuous bubbling, sometimes backwash and relaxation	Continuous bubbling	Small footprint; complete solid-liquid separation; high volumetric organic removal rate; higher effluent quality

6. PRESSURIZED VS. SUBMERGED FILTRATION SYSTEMS

While both pressurized and submerged systems utilize membranes to treat feedwater, the similarities between the systems end there, as they differ in infrastructure requirements, operating structure and capabilities, maintenance needs and lifetime cost.

6.1. Range of Operating Pressure

The primary difference between pressure and submerged systems is that pressure systems can operate within a large pressure range, while submerged systems are limited to atmospheric pressure. Submerged systems may operate at average pressures approaching 70% (10 to 11 psi at sea level) of the maximum pressure differential available. Pressure systems typically operate at 30% to 50% (12 to 20 psig) of the maximum trans-membrane pressure when tested on the same waters. This builds an intrinsic safety factor into a design, allowing the pressure system to cope with process upset, changes in influent water quality, or other changes in plant operation.

Broadly, the reliance on atmospheric pressure hampers submerged systems if they are installed at elevations higher than 4,000 ft., where atmospheric pressure becomes noticeably reduced. For example, in an application at 4,000 ft. above sea level, atmospheric pressure drops from 14.7 to 12.7 psi. Lower atmospheric pressure means less available differential pressure, translating into lower fluxes, larger footprint and higher costs.

6.2. Varying Permeate Flux Capabilities & Energy Consumptions

For submerged membranes, the maximum flux rate is 25 to 30 L/m².h (15 to 18 gfd). As discussed previously, to accomplish this flux, there is a common requirement to back pulse the membranes every 15 seconds with the treated water which results in the back-pulse water being added back to the water to be treated on the upstream side of the membrane. This back pulsing causes a significant net flux reduction of approximately 20% less than the feed flux rate. If the feed flux rate is 25 L/m².h then the net flux rate would be 20 L/m².h. In addition, submerged systems rely on a maximum TMP of 0.7 to 0.9 bar (10 to 12 psi) due to the limitation of a vacuum. With this TMP, energy

consumption is very low compared to conventional pressure membranes but membrane area for submerged membranes is very high. Membrane area affects capital costs and major cleaning or replacement costs if necessary.

Compared to submerged membranes, pressure UF membranes can operate with TMPs as high as 5 bar (75 psi). As result flux rates will be higher at 50 to 100 L/m².h (29 to 59 gfd). To accomplish these higher flux rates, feed water to the membranes should be coagulated and settled (clarity less than 3.0 NTU). Energy (Electricity) consumption for pressure UF membranes can range from 3 to 5 kwh/m³. Compared with pressurized membrane systems, submerged membrane processes have significantly lower operating costs.

The ability to treat water in cold climates is another differentiator between the two types of systems. In winter, feedwater temperatures drop, increasing viscosity and the driving force required to force water through a membrane pore. This affects submerged systems, since their maximum differential pressure is limited by atmospheric pressure, forcing submerged systems to be sized at lower fluxes.

For pressurized membrane systems, cold water is not a problem. By holding the flux constant, the higher viscosity of the water slightly increases differential pressure, which the pressurized system can accommodate. By the very nature of their operation, pressure systems operate in a wider differential pressure range (0 to 40 psid). This allows them to provide consistent flows, regardless of feedwater temperature.

6.3. Integrity Testing & Broken Fiber Repair

When it comes to integrity testing of a membrane fiber, pressure systems have several advantages. They use the pressure decay test, an automated and widely accepted procedure. Membrane fibers also can be pressurized more than 2.5 times those in a submerged system. This enables small breaches of membrane integrity to be detected easily and rapidly.

In a pressure system, each module is equipped with a clear coupling on the filtrate side. This allows a plant operator to quickly identify the module with the broken fiber. In

the rare instance when a broken fiber has been found, an operator can identify and repair it in less than 30 minutes.

Submerged systems often utilize the bubble point test or particle counting method. Identification and repair of leaked fibers in these systems require the removal of the module bundles from the basin, resulting in downtime.

6.4. Infrastructure Requirements & Operation

When converting from conventional treatment to UF/MF, the existing basins can be used to accommodate a submerged system. In this case, a submerged system may offer lower capital costs compared to a pressure system retrofit. However, if there are no available basins, the civil construction costs must be accounted for as part of the overall cost.

Another cost factor for submerged system is installation of an overhead crane to remove membrane cassettes from the basin. Pressure systems do not require basin construction or lifting mechanisms and can be installed on a concrete pad.

Submerged and pressure membrane systems offer excellent solids and pathogen removal to meet drinking water standards or provide protection for downstream equipment in reuse applications. Both systems provide high-quality filtrate regardless of variations in incoming water conditions, as long as the membranes are intact. Thus, you should check with suppliers on fiber breakage rates in actual service.

In currently available equipment, submerged systems tend to accommodate larger modules than pressure-vessel systems. Furthermore, submerged systems have substantially fewer valves and piping connections. As larger membrane plants are designed and built, membrane manufacturers have tried to improve the economy of scale by developing larger modules to reduce the number of individual modules and piping connections necessary in large facilities, and these trends are expected to continue to lead to the development of larger modules.

Submerged systems have been promoted and used for large systems and for high solids/poor quality feed sources. Material advances, process optimization, and an

increase in experience treating different types of waters have allowed pressure systems to effectively compete in these applications.

6.5. Fouling Rate

In terms of fouling rates, the efficiency of the submerged module was better than that of the pressurized module. This may be attributed to the compaction of foulant layer due to the external pressure in the pressurized module at fixed permeate flux.

7. MEMBRANE BIOREACTORS

Membrane bioreactor (MBR) technology, which combines conventional activated sludge treatment with low-pressure membrane filtration, is widely used for the treatment of wastewater. The considerable growth of MBR is driven by the high quality of the water produced, increased water scarcity, and decreasing specific energy requirements.

7.1. Anaerobic membrane bioreactor (AnMBR)

The anaerobic membrane bioreactor (AnMBR) is a subclass of MBRs that has great potential for improving wastewater treatment process efficiency and sustainability. The primary advantages to wastewater treatment by AnMBRs are the inherent aspects of the bioprocess that allow for low energy expenditure and potential for energy harvesting. The use of an anaerobic reactor eliminates the requirement of aeration for treatment while also introducing the potential for recovery of methane generated by anaerobic digestion. Additional advantages to the application of AnMBRs are their low solid waste production and a small reactor footprint due to higher anaerobic degradation rates while still maintaining high quality effluent by the use of membrane filtration. AnMBRs also serve to consolidate and/or eliminate many of the steps in conventional wastewater treatment, including activated sludge aeration, secondary clarification, and sludge digestion (see [Figure 7](#)).

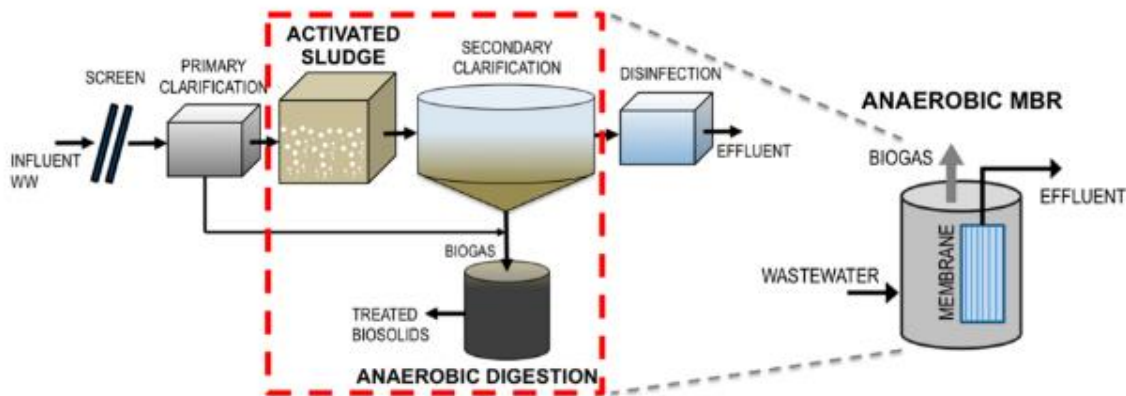


Figure 7

Schematic diagram of anaerobic MBR (AnMBR) potential to reduce central wastewater treatment plant processes and footprint. AnMBR can be used to replace activated sludge, secondary clarification and anaerobic digestion (i.e., processes enclosed within the red dashed line), hence reducing the footprint of a wastewater treatment plant.

A small footprint, complete solid-liquid separation, high volumetric organic removal rate, and higher effluent quality are some of the key advantages of the MBR and AnMBR. In the submerged hollow fiber MBR, the membranes are directly immersed in the aeration tank. The results of many industrial and municipal operations, demonstrate high treatment efficiencies for chemical oxygen demand (COD), total suspended solids (TSS), and turbidity. Although the MBR technology has been applied in many full-scale plants worldwide for treating municipal and industrial wastewater, membrane fouling and correspondingly increased energy consumption remain chief obstacles. Specifically, because membrane fouling diminishes productivity, fouling mitigation measures such as air scouring and frequent cleaning of the membrane are needed to restore the membrane permeability, which increases the energy requirement furthermore, and frequent cleaning shortens the membrane lifespan and results in higher membrane replacement costs. Aeration, bubbling, or gas sparging are the most common methods for mitigating membrane fouling.

7.2. Aerobic membrane bioreactors (AMBRs)

Aerobic membrane bioreactors (AMBRs), subclass of MBRs, are one of the leading technologies to achieve sustainability in wastewater treatment through reuse, decentralization, and low energy consumption. In aerobic MBRs, aerated activated sludge is coupled with membrane process to remove dissolved contaminants (carbon and ammonia) and separate solids from the treated municipal or industrial wastewater. Carbon is removed by microorganisms that metabolize the carbon in the presence of dissolved oxygen for microbial growth and respiration (organic carbon reduced to carbon dioxide). Ammonia is removed through ammonia oxidation (nitrification). Nitrification is a microbially mitigated reduction process that occurs in an aquatic environment that contains moderate to high concentrations of ammonia and dissolved oxygen and low concentrations of organic carbon.

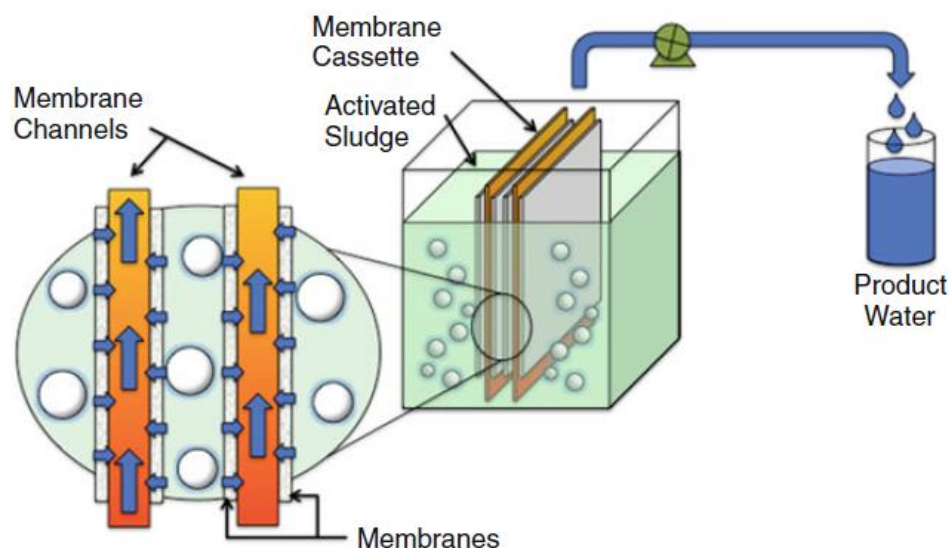


Figure 8

Schematic representation of a submerged aerobic MBR system.

In submerged MBRs ([Figure 8](#)), microporous MF or UF membranes are immersed in a bioreactor, and water is filtered (Permeate) through the membranes using vacuum; suspended solids are retained in the system; and high levels of treatment (including

nutrient removal) can be achieved. The MBR replaces the two-stage conventional activated sludge process (biotreatment and clarification) with a single, integrated process. The advantages of MBRs over conventional treatment includes product consistency, reduced footprint, reduced sludge production, and nearly complete suspended solid separation from the effluent. Additionally, MBR effluent may be suitable for use as irrigation water, as process water, or as a pretreatment for potable reuse applications.

However, the establishment of membrane bioreactor technology has been slower than expected because decision makers view MBRs as high risk and costly compared to conventional technology. To date, MBRs have been used to treat municipal and industrial wastewater where water reuse is desired, a small footprint is required, or stringent discharge standards exist.

7.3. Operation

Operation In order to operate conventional MBRs at constant flux, physical membrane-cleaning techniques are utilized; they include air scouring, backwashing, relaxation, or a combination of the three, depending on the membrane configuration (hollow fibers, flat sheet, or tubular). Air scouring is required for submerged MBR configurations to gas lift fresh sludge through the membrane bundle or cassette and to scour solids from the membrane surface. During backwashing, permeate is pumped in the opposite direction through the membrane, effectively removing most of the reversible fouling. Frequency, duration, and intensity are the key parameters affects the efficiency of backwashing. During membrane relaxation, permeate suction is stopped, and the back transport of foulants is naturally enhanced as reversibly attached foulants diffuse away from the membrane surface.

Membrane backwashing and relaxation are regularly used for tubular and hollow fiber membranes to control fouling. This is not the case for flat-sheet membranes that cannot be backwashed due to their inability to withstand pressure in the opposite direction of the operating flow; for this reason, relaxation is used to control the fouling of these membranes. Regardless of the membrane configuration, chemicals must be used at regular intervals to enhance physical cleaning.

7.4. Current Limitations - Fouling

One of the major limitations to widespread application of MBR technologies is to control membrane fouling with modest energy and chemical input. Fouling markedly affects membrane cleaning and replacement intervals, system productivity, and membrane integrity; all of which are factors that affect energy requirements and costs.