Application of Membrane Technology to the Production of Drinking Water

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Summary: Membrane technology has been used in Florida, Texas and California for the production of drinking water from groundwater sources. Current drinking water regulations and the proposed Long Term 2 Enhanced Surface Water Treatment Rule may drive many utilities, which currently use only conventional treatment technology to treat surface water, to switch to membranes—or add a membrane process to treatment. Blending of membrane treated water with conventionally treated water may be necessary to meet the water quality objectives. Many factors, like stricter drinking water quality standards, population movements to arid areas, or increased knowledge of pollutants may contribute to the need to utilize membranes in lieu of conventional treatment technologies. Because many pollutants may not be removed by conventional treatment, membrane technology may be the best solution for meeting future regulatory requirements. Membranes can play a part in meeting increasing demands for clean drinking water through, desalination of salt waters, increased use of surface water and reclamation of wastewater. This paper provides an understanding of membrane types used in drinking water, their application and pollutants removed by membranes.

https://wcponline.com/2004/08/14/application-membrane-technology-production-drinking-water/#:~:text=Membranes%20are%20becoming%20increasingly%20popular,and%20removing%20salt%20from%20seawater

Membranes are becoming increasingly popular for production of potable drinking water from ground and surface water sources, as well as for treatment of wastewater used for recharging groundwater aquifers and removing salt from seawater. Membranes are porous materials that allow water to pass through, while rejecting particles and dissolved pollutants. Several manufacturers produce a variety of membrane products, among the major producers being Dow/Filmtec, Hydranautics, Koch/Fluid Systems, Zenon, GE Osmonics/Desal, Toray and TriSep.

Types of membranes

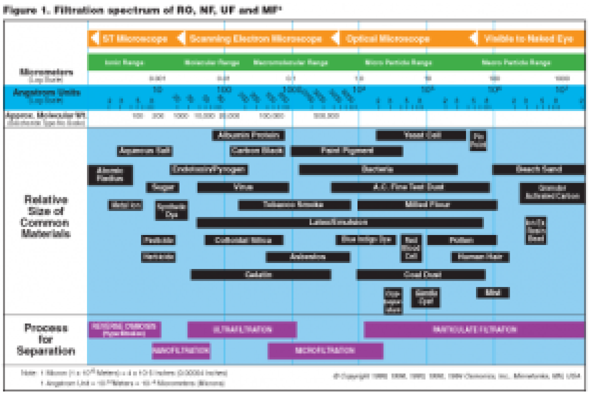
Membrane modules are made in the following configurations: spiral wound, tubular, plate-and-frame and hollow fiber. The solution coming into the module is defined as the feed and the solution that passes through the membrane is defined as permeate. The solution that exits the module without passing through the membrane is defined as the retentate ("concentrate").

Spiral wound modules consist of a sandwich of thin film composite membrane and porous support layers which is wrapped around a collection tube. The feed flows into the feed spacers at one end of the spiral sandwich, the permeate flows through the membrane into the permeate spacer and then is collected in the collection tube, and the retentate exits from the feed spacers at the opposite end of the spiral sandwich.[1] Tubular modules consist of a thin-film membrane supported inside a tube. The feed flows into the tube, permeate is collected from the space outside the tube, and the retentate exits from the opposite end of the tube.[2] Hollow fiber modules consist of capillary membrane fibers bundled inside the module. The feed flows into the module, the permeate flows into or out of the hollow fibers and is collected, and the retentate exits the module.[2]

Membrane separations can be divided into four categories: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). Each of these processes relies on pressure and size

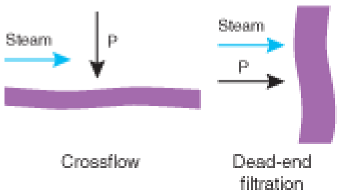
exclusion to filter the water. Separation is based on the pore size with microfiltration having the "loosest" pores and reverse osmosis having the "tightest" pores. As the pore size becomes smaller, the membrane becomes tighter. As a result, higher pressure is needed to force the water through it. Both RO and NF change the chemical—or ionic—nature of the raw water to produce the product water, whereas UF and MF are classic particle removal processes.[3]
The filtration spectrum of RO, NF, UF and MF relative to sizes of common materials is shown in Figure 1.[4]

Figure 1. Filtration spectrum of RO, NF, UF and MF[4]



Microfiltration
MF separates particles of size 0.1 microns (μm) through 10 μm. MF membranes have received particular attention because of their ability to remove turbidity, particles and coliform bacteria. Although MF isn't a serious obstacle for viruses, when used in conjunction with a disinfection process, it can control microorganisms in the feed water. MF includes two common forms of filtration: crossflow separation and dead-end filtration (see Figure 2).[5]

Figure 2. Crossflow and dead-end filtration processes[5]



In crossflow separation, a fluid runs parallel to a membrane. There's some pressure involved across the membrane, which causes some of the fluid to pass through the membrane, while the remainder continues to move across the membrane, cleaning it. In dead-end filtration, or perpendicular filtration, all of the fluid passes through the membrane, and all of the particles that cannot fit through the pores of the membrane are stopped.[17]
The MF process involves the screening of raw water and pumping it into a membrane under low pressure.[6] MF provides absolute removal of particulate contaminants from feed water by separation, which is based on retention of particles on a membrane surface. Because of the large pore sizes, MF can be used for removal of particles and some microbes and can be operated under low-pressure conditions (i.e., low cost). MF can be used as an alternative to conventional treatment for removal of waterborne pathogens. One example is the waterborne pathogen *Cryptosporidium parvum*, which is associated with serious diseases and resistant to traditional disinfection treatment with chlorine. MF has another advantage over conventional treatment: 1) It reduces the number of unit processes for clarification, and 2) it increases plant compactness and process automation. With the same water treating capacity, MF plants can be much smaller than conventional plants. In addition, the MF process (as well as any other membrane process) produces less sludge since it doesn't use chemical coagulants or polymers.
In process, membranes can get fouled. Once fouled, the solids must be removed or backwashed to clear the debris from the membrane.

Ultrafiltration

UF, first developed in 1972, is very similar to MF in its general set up and operational process.[1] The pore size in UF is anywhere from .002 to 0.1 μm and is operated under a pressure ranging from 30 to 100 pounds per square inch (psi).[6] UF is capable of removing many species of bacteria and some viruses but it does allow most ionic inorganic species to pass through.[6] UF, like MF, is subject to membrane fouling and will require periodic backwashing (depending on the form of membrane or particular manufacturer, as not all may be back washable). Advantages over conventional treatment are similar to those of MF.

Using UF, the membrane unit can be submerged in water and suction pressure can be used to pull the water across the membranes (outside-in flow).[7] After passing through the UF units, the water can be disinfected by chlorination, UV inactivation or ozonation. While UF systems can stand alone to produce high quality water, coupling the membrane systems with other technologies can greatly enhance efficiency, reduce membrane fouling and optimize treatment based on the quality of the source water.

Nanofiltration

NF uses a pore size of up to 1 nanometer (0.0001-0.001 μm). Used primarily for membrane softening, NF is increasingly being used for removal of bacteria and other pathogens, particulate matter and natural organic matter (NOM).[8] NF is one of the viable alternatives to conventional treatment of potable water, primarily because NF plants can operate at relatively low pressures from 600 to 1000 kilopascals (kPa), or about 90-150 psi.[9] Membrane filters retain particles on the surface within a depth of 10-15 μm and typically have 400-500 million pores per square centimeter.[10] The spiral wound configuration is usually used for NF. Each unit is typically 40-60 inches long and 2.5-8.5 inches in diameter, and the active surface area ranges from 20 square feet (ft2) to more than 500 ft2.[11]

Reverse osmosis

To understand RO, the process of osmosis must be understood. Osmosis is the transport of solvent through a semipermeable membrane, which separates two solutions of different solute concentrations. The direction of flow is from the dilute solution to the concentrated solution.[13] This process occurs as a result of thermodynamic laws that are attempting to achieve the same solute concentration on both sides of the membrane.

According to Van't Hoff equation, the osmotic pressure of a dilute solution can be described as following equation, which is very similar to the ideal gas equation.[14]

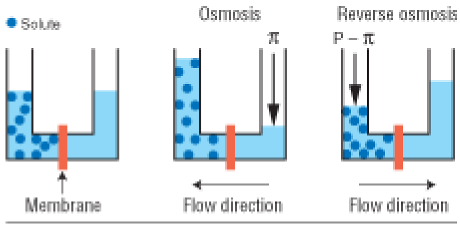
$\pi V = n R T$ where: π = osmotic pressure
V = solvent volume
n = number of moles of solute
R = gas constant
T = temperature in Kelvin

If this equation is rearranged to solve for p and solute-solute interactions that reduce the activity of the solute are taken into consideration, the result is following equation.[15]

$\pi = G C R T$ where: C = molar concentration
G = osmotic coefficient (for non-ideal interactions)

If certain pressure (P) is applied to the concentrated solution side of the membrane that's greater than the osmotic pressure (p), then the direction of flow can be reversed. This is the underlying principal of reverse osmosis, and is illustrated in Figure 3.

Figure 3. The underlying principle of reverse osmosis

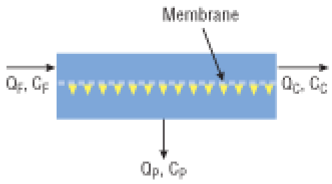


RO retains contaminants less than 10-4 (<0.0001) µm. Therefore, RO membranes are capable of rejecting bacteria, salts, sugars, proteins, particles, dyes and other constituents that have a molecular weight greater than 150-250 daltons. RO membranes, like all membranes, are prone to fouling by "cake layer" formation, a buildup of suspended solids or other non-soluble contaminants at the membrane's surface.[16]

Membrane mechanisms

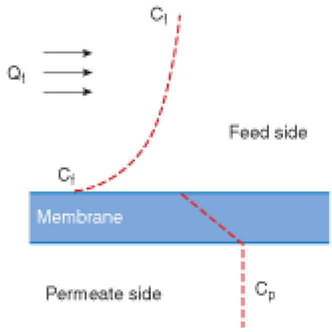
All membrane technologies are pressure-driven processes. Molecules pass through the membrane by diffusion. The unit is divided into two cells by the membrane. The feed water is pressurized and introduced into one of the two flow cells at a flow rate of Qf (see Figure 4).

Figure 4. Diagram of membrane separation process



In the cell, the water flows parallel to the membrane at high velocities and some is forced by the high pressure through the membrane to the permeate side at a flow rate of Qp. The water permeates through the membrane at a faster rate than the solutes and so a rejected concentration gradient develops. This process is called concentration polarization and results in solute concentrations next to the membrane (Cw) being greater than the bulk feed concentrate (Cf) (see Figure 5).

Figure 5. Diagram showing concentration polarization



The behavior of the membrane process is dependent on several factors, such as concentration polarization, membrane fouling, membrane charge and feed water content. Fouling of the membrane, which is defined as loss of flux across the membrane, can reduce performance by as much as 90 percent.[12]

Conclusion

This paper has described four types of membranes (MF, UF, NF and RO), explored their applications in drinking water production and compared membrane technology to conventional treatment. Stricter regulations and demand for more water may require membrane technology for production of drinking water. Some factors, like cost-benefit analysis were not included in this study, although manufacturing and other efficiencies in production of membranes have resulted in membranes being much more economical in recent years, thus broadening practical applications for the technology.

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