Potable Water - Membrane Filtration

An Online Continuing Education Course for Engineers

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Introduction

A membrane or, more properly, a semi-permeable membrane, is a thin layer of material capable of separating substances when a driving force is applied across the membrane.

Once considered a viable technology only for desalination, membrane processes are increasingly employed for removal of bacteria and other microorganisms, particulate material, and natural organic material, which can impart color, tastes, and odors to the water and react with disinfectants to form disinfection byproducts (DBP). As advancements are made in membrane production and module design, capital and operating costs continue to decline.

The pressure-driven membrane processes discussed in this course are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO).

Membrane Filtration: Alternative to Conventional Filtration

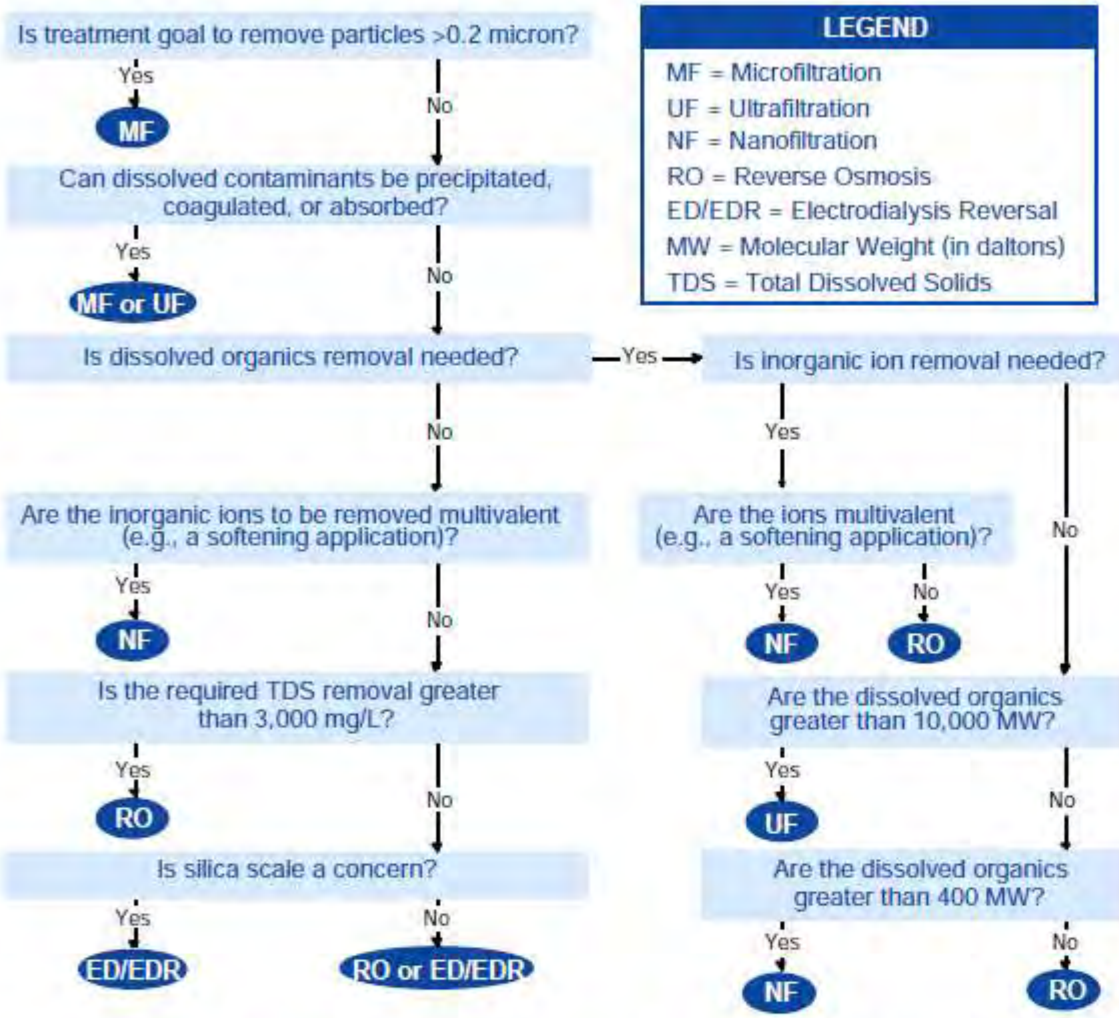
Membrane filtration systems' capital costs, on a basis of dollars per volume of installed treatment capacity, do not escalate rapidly as plant size decreases. This factor makes membranes quite attractive for small systems. In addition, for groundwater sources that do not need pretreatment, membrane technologies are relatively simple to install, and the systems require little more than a feed pump, a cleaning pump, the membrane modules, and some holding tanks. According to a report by the National Research Council, most experts foresee that membrane filtration will be used with greater frequency in small systems as the complexity of conventional treatment processes for small systems increases.

New Regulations Favor Membrane Technologies

Membrane processes have become more attractive for potable water production in recent years due to the increased stringency of drinking water regulations. Membrane processes have excellent separation capabilities and show promise for meeting many of the existing and anticipated drinking water standards. The Surface Water Treatment Rule (SWTR) and the Groundwater Disinfection Rule have led to the investigation of UF and MF for turbidity and microbial removal. The Disinfectants/Disinfection Byproduct (D/DBP) rules have increased interest in NF and UF membranes for DBP precursor removal.

Potable water treatment has traditionally focused on processes for liquid-solid separation rather than on processes for removing dissolved contaminants from water. Thus, the effect of the Safe Drinking Water Act (SDWA) amendments has been to encourage water treatment professionals to consider the more unconventional treatment processes, such as membrane technologies, alone, or in conjunction with liquid-solid separation, to meet current regulations.

Figure 1: Generalized Membrane Process Selection Chart



NOTE: This simplified chart is based on common assumptions and should not be applied to every situation without more detailed analysis.

ASSUMPTIONS

A. Relative Cost
- MF < UF < NF < RO or ED/EDR
- If TDS removal > 3,000 mg/L, RO or ED/EDR may be less costly

B. Removals
- MF–particles > 0.2 Micron
- UF–organics > 10,000 MW, virus, and colloids
- NF–organics > 400 MW and hardness ions
- RO–salts and low MW organics
- ED/EDR–Salts
- Particles include *Giardia*, *Cryptosporidium*, bacteria, and turbidity

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Comparing Membrane Filtration Systems

While all types of membranes work well under proper conditions, choosing the most appropriate membrane for a given application still remains crucial. (See Figure 1.) In many cases, selection is complicated by the availability of new types of membranes, applications, or by site-specific conditions. Bench and pilot tests are powerful tools for situations where process risks and uncertainties exist or the cost impacts from problems are potentially high.

Membrane classification standards vary considerably from one filter supplier to another. What one supplier sells as a UF product, another manufacturer calls a NF system. It is better to look directly at pore size, molecular weight cutoff (MWCO), and applied pressure needed when comparing two membrane systems. MWCO, which can be regarded as a measure of membrane pore dimensions, is a specification used by membrane suppliers to describe a membrane's retention capabilities.

Microfiltration (MF)

MF is loosely defined as a membrane separation process using membranes with a pore size of approximately 0.03 to 10 microns, a MWCO of greater than 100,000 daltons, and a relatively low feedwater operating pressure of approximately 100 to 400 kPa (15 to 60 psi). Representative materials removed by MF include sand, silt, clays, Giardia lamblia and Cryptosporidium cysts, algae, and some bacterial species. (See Figure 2 and Table 1.) MF is not an absolute barrier to viruses; however, when used in combination with disinfection, MF appears to control these microorganisms in water.

The primary impetus for the more widespread use of MF has been the increasingly stringent requirements for removing particles and microorganisms from drinking water supplies. Additionally, there is a growing emphasis on limiting the concentrations and number of chemicals that are applied during water treatment. By physically removing the pathogens, membrane filtration can significantly reduce chemical addition, such as chlorination.

Another application for the technology is for removal of natural or synthetic organic matter to reduce fouling potential. In its normal operation, MF removes little or no organic matter; however, when pretreatment is applied, increased removal of organic material, as well as a retardation of membrane fouling can be realized.

Two other applications involve using MF as a pretreatment to RO or NF to reduce fouling potential. Both RO and NF have been traditionally employed to desalt or remove hardness from groundwater.

PROCESS

MF membranes provide absolute removal of particulate contaminants from a feed stream by separation based on retention of contaminants on a membrane surface. It is the "loosest" of the membrane processes, and as a consequence of its large pore size, it is used primarily for removing particles and microbes and can be operated under ultralow pressure conditions.

In the simplest designs, the MF process involves prescreening raw water and pumping it under pressure onto a membrane. In comparison to conventional water clarification processes, where coagulants and other chemicals are added to the water before filtration, there are few pretreatment requirements for hollow-fiber systems when particles and microorganisms are the target contaminants.

Prefilters are necessary to remove large particles that may plug the inlet to the fibers within the membrane module. More complex pretreatment strategies are sometimes employed either to reduce fouling or enhance the removal of viruses and dissolved organic matter. In such cases, pretreatment by adding coagulants or powdered activated carbon (PAC), has been employed. In some cases, the cake layer built up on the membrane during the water production cycle can remove some organic materials.

It may be necessary to adjust the feedwater pH by chemical dosing prior to membrane filtration in order to maintain the pH within the recommended operating range for the membrane material employed. It should be noted that pH adjustment is not required for scaling control, since MF membranes do not remove uncomplexed dissolved ions.

MF membranes, under the most conservative conditions, appear to act as an absolute barrier to selected bacteria and protozoan cysts and oocysts. Unlike UF however, MF does not remove appreciable densities of viruses. Therefore, it is necessary to complement MF with a post-membrane disinfection process. Chemical disinfection may be employed by applying chlorine, chlorine dioxide, or chloramines; however, long contact times are required to inactivate viruses.

EQUIPMENT

For municipal-scale drinking water applications, the commercially available membrane geometries that are the most commonly employed are spiral wound, tubular, and hollow capillary fiber. However, spiral-wound configurations are not normally employed for MF due to the flat-sheet nature of the membrane, which presents difficulties in keeping the membrane surface clean. Unlike spiral-wound membranes, hollow-fiber and tubular configurations allow the membrane to be backwashed, a process by which fouling due to particulate and organic materials is controlled.

Membrane “package” plants are normally employed for plants treating less than one million gallons per day (mgd). The components of the plant may include prescreens, a feed pump, a cleaning tank, an automatic gas backwash system, an air compressor, a membrane integrity monitor, a backwash water transfer tank, a pressure break reservoir, an air filter for the gas backwash, controls for the programmable logic controller, and a coalescer.

OPERATION AND MAINTENANCE

In MF, there are two methods for maintaining or re-establishing permeate flux after the membranes are fouled:

- Membrane backwashing: In order to prevent the continuous accumulation of solids on the membrane surface, the membrane is backwashed. Unlike backwashing for conventional media filtration, the backwashing cycle takes only a few minutes. Both liquid and gas backwashing are employed with MF technology. For most systems, backwashing is fully automatic. If backwashing is incapable of restoring the flux, then membranes are chemically cleaned. The variables that should [...] in cleaning MF membranes include: frequency and dur[...] their concentrations, cleaning and rinse [...] use of cleaning chemicals, neutralizat[...]
- Membrane [...] loyed to improve the level of removal [...] d to increase or maintain transmemb[...] ost common types of pretreatmen[...]

Ultrafiltration (UF

UF involves the pres[...] g a membrane pore size of approximately 0.0[...] 000 to 100,000 daltons, and an operating pres[...] si). UF will remove all microbiological speci[...] well as some viruses (but not an absolute b[...] and Table 1.) Disinfection can provi[...] e recommended.

The primary advantage[...] ompared with conventional clarification and disinf[...] esses are:

- No need for chemicals (coagulants, flocculants, disinfectants, pH adjustment);
- Size-exclusion filtration as opposed to media depth filtration;
- Good and constant quality of the treated water in terms of particle and microbial removal;
- Process and plant compactness; and
- Simple automation.

Fouling is the limiting phenomenon responsible for most difficulties encountered in membrane technology for water treatment. UF is certainly not exempt from this fouling control problem.

Therefore, membrane productivity is still an important subject, which should be thoroughly researched in order to have a better understanding of this phenomenon and its mechanisms.