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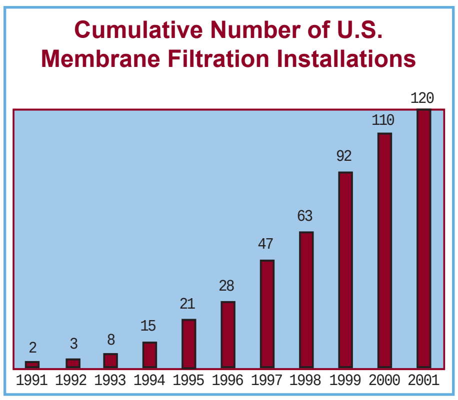
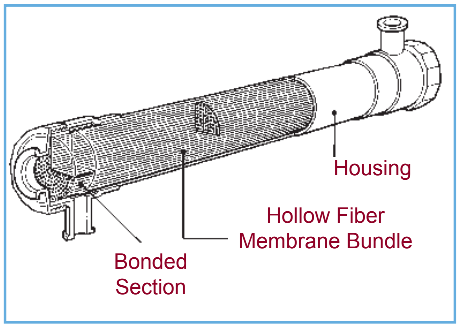
A Primer on Membrane Filtration for Community Water Systems

Drinking water filtration technology is at a historic crossroads. Until the last several years, surface water treatment meant using slow sand or, more typically, rapid sand filtration. Other than a few refinements along the way, surface water filtration technology has changed little since becoming prevalent in the late 1800s. Now membrane filtration is well on its way to becoming the most common type of filtration for new surface water treatment facilities. The cumulative number of new membrane systems built in the U.S. from 1991 through 2001 is shown on the following chart:



Why the big change? Well, first it might be helpful to define membrane filtration. Membrane filtration is a pressure driven process that uses a semi-permeable (porous) membrane to separate particulate matter from water. Membranes act much like a very fine sieve to retain particulate matter, while water and its soluble components pass through the membrane as filtered water. The retained solids are concentrated in a waste stream that is discharged from the membrane system. The pore size of the membrane controls the size of the particulate matter that is removed. Membranes having a smaller pore size remove more very small matter, such as bacteria and parasitic cysts.

The two types of membranes used for surface water filtration are microfiltration and ultrafiltration. Microfiltration generally removes pathogens down to a size of 0.1 microns, including giardia, cryptosporidium, bacteria, but not viruses, which are smaller than 0.1 microns. Ultrafiltration, generally rated for 0.01 micron particle removal,



removes all pathogens including viruses. Both types of systems are constructed of thousands of hollow fibers bundled together inside of cartridges. The walls of the fibers contain synthetic material that provides the filtration. Depending on the manufacturer, raw water flows from the outside of the hollow fibers to the inside, leaving the particles on the outside of the membrane, or, in some cases, starts on the inside of the fibers and flows outward.

Fiber Cross Section

The theory behind membrane filtration is quite simple: the smaller the pore size, the smaller the particle that can be removed. Rapid sand filtration, on the other hand, is considerably more complicated and cannot be explained as a mere sieve process. It relies heavily on chemical pretreatment to both destabilize particles in water and to agglomerate smaller particles into much larger ones. There's not enough space here to adequately describe the theory of rapid sand filtration. Suffice to say, without adequate chemical pretreatment of water, rapid sand filtration will not provide adequate water quality. Thus, rapid sand filtration is only as reliable as its weakest link, which is the chemical pretreatment step. And, because of the importance and complexity of chemical treatment, the process does not lend itself well to automation.

Regulatory Issues May be Partially Driving Market

In the aftermath of the well publicized 1993 epidemic in Milwaukee caused by cryptosporidium that had passed through a rapid sand filtration plant, EPA has proposed more stringent requirements for water systems that have high concentrations of cryptosporidium in their raw water. The more vulnerable systems may have to either augment or replace rapid sand filters with equipment such as membrane filtration that can provide more reliable removal of cryptosporidium. Given the uncertainty regarding where they fit into the proposed regulations, some water utilities have probably assumed that it is a safer bet to use membrane filtration at new facilities.

Upside and Downside

The following are some advantages of membrane filtration compared to rapid sand filtration:

- It provides a positive barrier to removal of pathogens such as giardia, cryptosporidium and bacteria
- Particle removal does not depend on chemical pretreatment, as is the case with rapid sand filtration
- There is less chemical usage and, in many cases, no chemical sludge is produced
- Space requirements are much smaller
- It is better suited to automation (because of simplicity and the fact that no chemical pretreatment is required)
- The cost is comparable to rapid sand filtration

Well, sounds good so far. But what, you might be asking, is the downside? One of the tenets of water treatment is the "multiple barriers" philosophy, which simply means that it is prudent to provide two or more treatment processes in series to provide multiple barriers. That way, in the event of a breakdown of one process, there is still a barrier to pathogen breakthrough via the other processes. In rapid sand filtration, the multiple barriers nor-

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mally include sedimentation, filtration and chlorine disinfection. For membrane filtration, the barriers are the membrane filters and chlorine disinfection. Because chlorine disinfection is not effective against cryptosporidium, the only barrier against this organism is the membrane, and, if the membrane fibers are damaged, harmful pathogens could pass into the treated water.

Fortunately, membrane manufacturers have developed membrane integrity tests. These are tests that the equipment automatically performs to verify that the membrane fibers are not damaged. The most common test is the air pressure hold test. This test involves using compressed air to verify the integrity of the membranes. This type of test can sense breakage in one fiber out of many thousands. The other instrument used for membrane integrity testing is the particle counter. This instrument is also quite effective in verifying membrane integrity. The Pennsylvania DEP typically requires both an air pressure hold test and filter effluent particle counters. Thus, because compromised membranes can readily be detected, there is little chance for breakthrough of harmful pathogens. It should also be mentioned that, even though rapid sand filtration provides an additional treatment barrier, the multiple barriers are imperfect. Unlike membrane filtration, which provides an absolute barrier based on the pores in the membrane, sand filters do not provide an absolute barrier. Instead, they rely on chemical conditioning to allow the sand particles to remove harmful pathogens.

While it is apparent that membrane filtration provides superior pathogen removal, usually surface water treatment involves additional water quality considerations, such as minimizing disinfection byproduct formation. Recently adopted regulations impose more stringent standards on disinfection byproducts (DBPs), including trihalomethanes and haloacetic acids. DBPs form when the naturally occurring organic carbon in the raw water reacts with chlorine used for disinfection. Methods of controlling DBPs include removing total organic carbon (TOC) in the treatment process, reducing chlorine concentration and reducing residence time in the distribution system. Removal of TOC entails adding a coagulant to the water prior to filtration to adsorb TOC. Various studies have indicated that membrane filtration can be just as effective as rapid sand filtration for TOC removal, assuming the proper coagulant and dosage is used. Another common water quality goal is to provide water that is aesthetically acceptable and free of taste and odor problems. Membrane filtration also meets this objective through the use of powdered activated carbon ahead of the filters to remove taste and odor causing compounds.

The earliest membrane installations were primarily used where there was pretty clean and consistent water quality, such as found on upland reservoirs. It was only a few years, however, until refinements in technology allowed membrane filtration to be applied to almost any type of water quality. The cleanest sources often involve providing only membrane filters followed by chlorine disinfection without any pretreatment. For the dirtier water sources, pretreatment, involving the addition of coagulant followed by a short retention in a mix tank, is provided prior to filtration. Although the coagulant is not necessary to enhance particle removal, it can reduce backwash frequency and provide for removal of some TOC.

Operation and Maintenance Issues

One of the principal maintenance costs is replacement of the membrane cartridges. Typical membrane life is 5 to 10 years, depending on the supplier, water flux rate and other variables. CET has estimated from several membrane projects that the membrane replacement costs are 5 to 10 percent of the total treatment costs (including capital depreciation). Membrane life is one of many variables that needs to be considered when selecting a membrane vendor.

Water recovery (water produced minus water used for backwash) is similar to that for rapid sand filtration and is usually in the range of 92 percent to 97 percent, depending on the manufacturer and water quality.

Pilot Testing is Often Warranted

Pilot testing can allow vendors to determine the optimum design loading rate thus potentially saving substantial capital costs, especially for larger facilities.

Although the Pennsylvania DEP has permitted several membrane filtration facilities, the DEP still classifies the process as "Innovative Technology", which usually involves pilot testing prior to permitting and increased monitoring after start-up. CET has overseen pilot testing at two facilities and found it to be very beneficial in terms of establishing design parameters and comparing equipment from multiple vendors. A number of different design parameters can be determined by pilot testing including flux rates, space requirements, pressure loss, and chemical types and dosages. Pilot testing can allow vendors to determine the optimum design loading rate thus potentially saving substantial capital costs, especially for larger facilities. Although pilot testing takes a lot of planning and coordination and can delay a project for up to a year, we recommend it in most cases. An exception is small systems that have fairly good and stable water quality. As manufacturers develop additional case history data for various kinds of waters, there may be fewer cases where pilot testing is warranted.

Summary

There are about a half dozen major membrane suppliers for surface water treatment in the U.S. All of them have demonstrated the ability to provide excellent pathogen removal, so the selection of the supplier depends on other issues such as water quality, capital cost, and membrane replacement costs. As the competition has increased, the prices for membrane systems have decreased.

So, should utilities automatically rule out rapid sand filtration for new plants and plant expansions? Not necessarily. The selection needs to be based on many factors, such as capital and operating cost, water quality, etc. CET's experience with the planning and design of several major rapid sand filtration projects over the last several years has shown that the technology is still capable of providing excellent water quality, assuming proper design and operation. And, some technological improvements to rapid sand filtration, such as new sedimentation basin and underdrain designs, have allowed for improved performance. For older rapid sand filter plants, we have found that these technological improvements provide for improved water quality and increased plant capacity within the same footprint of the existing plant for a cost far less than replacing the plant with membrane filtration. In other cases, however, membrane filtration may be the best choice. CET has completed the design of the three membrane filtration plants. Although none have been constructed yet, two of them have been permitted by the DEP and construction should begin soon. We look forward to discussing the full scale operation of these facilities in a future issue of ***etcetera***.

If you have any questions or need additional information, please contact:

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