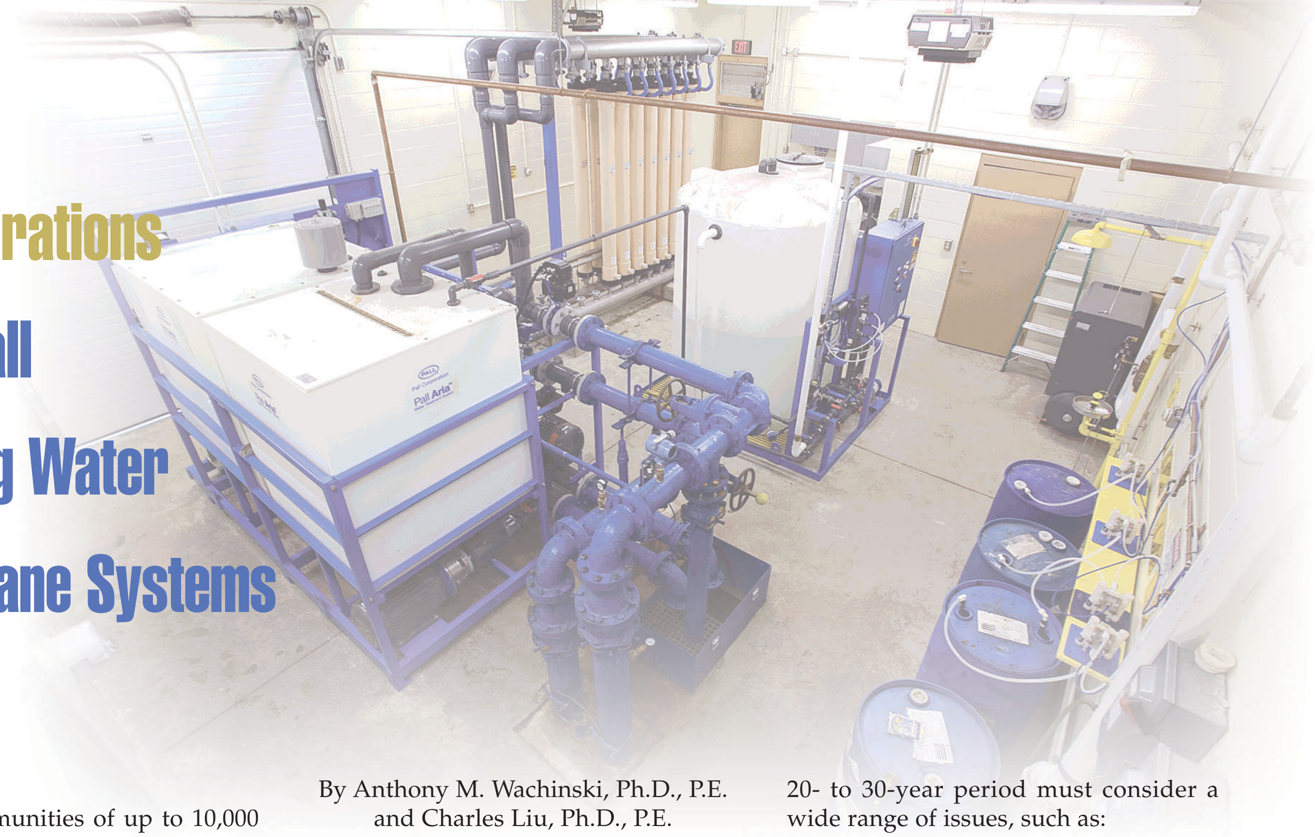
Design Considerations for Small Drinking Water Membrane Systems



By Anthony M. Wachinski, Ph.D., P.E. and Charles Liu, Ph.D., P.E.

Abstract

Small communities of up to 10,000 people typically utilize up to one million gallons of potable water daily. Microfiltration (MF) membrane technology provides a unique design solution for such communities. This is especially true in remote locations where space and personnel are limited and where environmental considerations restrict or prohibit chemical and/or sludge disposal. Small-system footprints allow retrofit into existing buildings or installation into prefabricated structures. Membrane systems are much less dependent upon operator attention than conventional filtration systems because they offer remote monitoring capabilities and system automation. High-quality drinking water (turbidity < 0.1NTU) can be assured by MF membranes, which effectively remove *Cryptosporidium* and *Giardia* and exceed *Surface Water Treatment Rule* (*SWTR*) log removal requirements.

Hollow-fiber MF membrane systems made of fluorocarbon, polyvinylidene fluoride (PVDF), provide comprehensive oxidant compatibility that allows the oxidation and subsequent removal of iron, manganese; taste and odor compounds are oxidized or removed by coagulants or powdered activated carbon. Automated integrity test procedures assure long-term membrane reliability.

Introduction

This article discusses design considerations for hollow-fiber MF membrane systems used to provide drinking water for small communities. Small systems are defined as million gallons-per-day (gpd) or a population equivalent of 10,000 people.

At this time, hollow-fiber MF membrane systems are the best available technology for small communities treating surface and groundwaters to meet *Safe Water Drinking Act* (*SWDA*) standards. Compared to conventional treatment technologies, MF systems require less space (smaller footprint), minimal chemical pretreatment, less operator attention and can be monitored and operated remotely. MF membrane systems with a nominal pore size of 0.1 micron provide a physical barrier to protozoa, such as *Cryptosporidium*, *Giardia* and to bacteria, such as *E. Coli.* This is significant because the recently published *Long-Term 2 Enhanced Surface Water Treatment Rule (LT2 ESWTR)* would require public water systems to have additional treatment to guarantee the safety of drinking water if their source water is subject to increasing risks of contamination by *Cryptosporidium*. Due to its high chlorine resistance and concerns associated with the formation of disinfection byproducts (DPBs), a conventional water treatment process such as chlorination cannot be used for compliance with the *LT2 ESWTR*. Therefore, low-pressure membranes such MF and ultrafiltration (UF) will play an important role for rule compliance.

Design considerations

The design of MF systems to successfully provide safe drinking water for a 20- to 30-year period must consider a wide range of issues, such as:

- System certification
- Quality assurance monitoring
- Membrane selection
- Operation
- Module design
- Other standards

System certification

In the US, small membrane systems should be NSF-61 System certified and should hold a third-party performance evaluation as defined by the US Environmental Protection Agency (US EPA)/ National Sanitation Foundation (NSF) Environmental Technology Verification (ETV) Program. NSF-61 system certification ensures the small community that its water treatment membrane system is constructed of materials that will not release harmful chemicals into the product water; the ETV report verifies the system performance claims made by the manufacturer. This verification should substantially reduce the need for pilot testing and review by regulatory agencies, which in turn reduces overall costs for the community.

Membrane selection

Membranes are defined and classified according to their nominal pore size or nominal molecular weight cutoff (MWCO). Nominal pore size refers to the smallest pore size in the membrane matrix. MWCO refers to the smallest molecule retained by the membrane, most often expressed in Daltons.

MF is a size-exclusion, pressure-driven membrane process that operates at ambient temperature. It is usually considered an intermediate between UF and multi-media granular filtration with pore sizes ranging from 0.10 to 10 microns. It is an effective barrier for particles, bacteria and protozoan cysts. It operates at pressures between 10 and 30 pounds per square inch (psi).

UF membrane systems retain particulate, bacteria, protozoa, viruses and organic molecules greater than their MWCO. They operate at pressures between 10 and 50 psi.

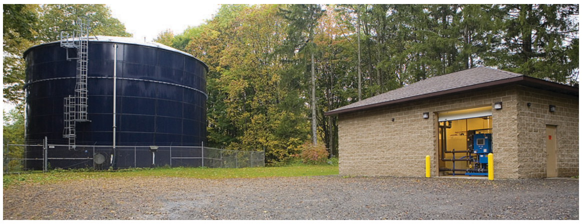
Nanofiltration (NF) membrane systems retain dissolved organic compounds in the range of 200 to 400 Daltons, essentially all multivalent cations and anions and a fraction of the monovalent species. NF membranes are often used to soften water. They effectively remove disinfection byproduct precursors such as humic acid. They operate at pressures between 50 and 150 psi.

Reverse osmosis (RO) membrane systems remove essentially all organic and inorganic constituents. They operate at pressures between 300 and 600 psi.

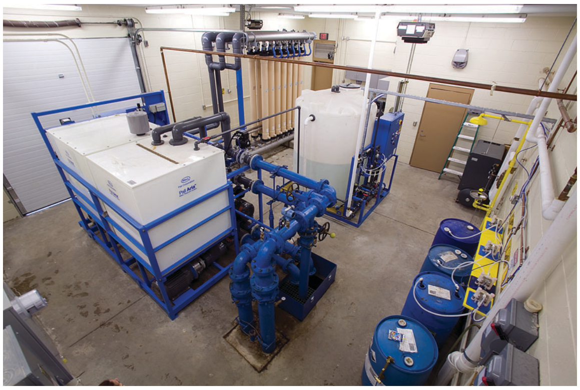
Compliance with the *SWDA* for small systems requires three-log reduction of *Cryptosporidium* and *Giardia* and four-log removal of viruses. *Cryptosporidium* and *Giardia* range in size from three to 15 microns. Viruses range in size from 0.02 to 0.08 microns. Although all membrane types are capable of meeting *SWDA*, RO and NF membrane systems are not cost effective at this time because their high power requirement and low flux cannot compete with MF, UF and conventional technologies.

UF membranes can remove cysts and most viruses with typical operating pressures lower than NF and RO and higher than MF. Fluxes are lower than MF and power consumption is higher due to crossflow operation. Properly designed UF membrane systems meet virus log removal requirements. UF membranes not made of PVDF may not tolerate oxidants well and because they offer a single-barrier approach to protozoa, bacteria and viruses with no redundancy, UF systems may present an integrity problem for small communities.

MF requires an additional disinfection step to remove viruses for municipal water treatment. With a nominal pore size of 0.1 micron, the MF membrane represents a barrier to protozoan cysts, oocysts and bacteria. Viruses have a very low tolerance for chlorine. At the typical temperature range (0 to 20°C; 32 to 68°F) and pH range (6 to 9) of drinking water, the Ct value (the product of disinfectant concentration and exposure time) to achieve four-log virus reduction is from three to 12 mg/L per minute. Therefore, for most small community drinking water systems, virus inactivation is not an issue. MF has been shown to provide



The Village of Groton, NY selected a Pall Aria AP system for drinking water treatment in their community.



cost-effective drinking water for small communities as an alternative to conventional filtration systems.

Configuration and module design

Hollow-fiber MF membranes are organic polymeric tubes (fibers) usually less than a millimeter in diameter, enclosed in a module. The fibers are sealed at the bottom end of the filter module in such a manner as to direct flow streams to the outside (shell side) of the fiber. The fibers are sealed at the top end of the filter module to allow filtered water to exit from the inside (lumen side) of the fiber. The water to be treated is pumped into the module and exits from the open ends of the lumens. A vertical configuration allows the use of gravity to separate air and water in the process. The number of hollow fibers housed in a module can be in the thousands; module length usually ranges from one to two meters. A pump upstream of the module pressurizes the shell side of the MF fiber. A hollow-fiber membrane made from PVDF has excellent oxidant resistance and can, therefore, be used after oxidation by chlorine, potassium permanganate, ozone or chlorine dioxide without having to neutralize the oxidant prior to the membrane. These membranes are hydrophobic. Cationic polyelectrolytes, if overdosed, tend to bind with the membrane. Hollow-fiber configured MF membranes operate in either a dead end mode or with some degree of recirculation. Flux ranges from 35 to 60 gallons per square foot per day (gfd) on surface water. On some treated waters, fluxes in excess of 75 gfd, computed for the outside/in configuration, have been documented using a 0.1-micron, PVDF microfiltration system. At these fluxes, operating pressures range from five psi for clean membranes to a maximum of 43.5 psi for fouled membranes. Process recovery is typically 95 percent for surface water and can be as high as 97 percent. MF membranes are typically cleaned chemically every one to three months on surface waters. PVDF membranes can be cleaned with strong acids, strong bases, chelating agents such as citric acid and oxidants such as chlorine or peracetic acid.

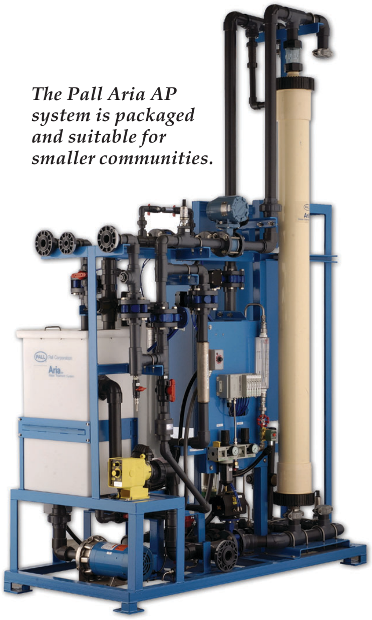
Operation

MF membrane systems are operated in the direct filtration mode (dead end), or with minimal recirculation. During operation, the feed water flow is normal to the membrane surface and, as such, suspended particulates and fouling species are retained on the membrane surface. Resistance to flow and the accumulation of solids on the shell side of the membrane surface result in an increase in the transmembrane pressure (TMP), which is the effective pressure across the membrane.

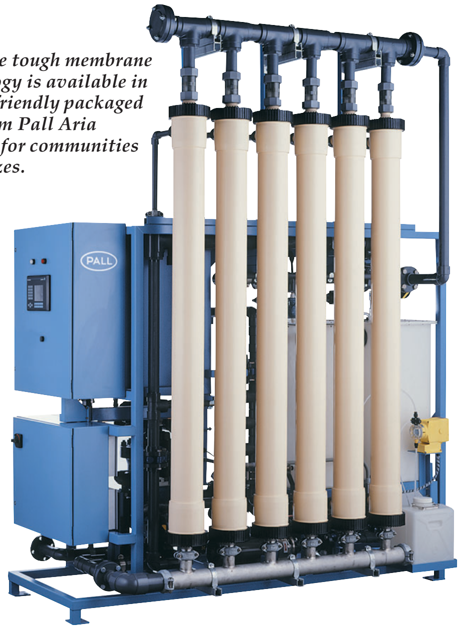
For a membrane system to effectively produce water for a small community, fouling species, which include particulates, microorganisms, chemical precipitates and other particulates, must be effectively removed from the hollow fiber surface. Techniques to accomplish this involve physical steps; e.g., reverse filtration (RF) or chemical steps which necessitate that the module be taken offline and out of service.

Reverse filtration (backwash)

Fouling species are removed from the PVDF membrane surface by reversing the direction of flow across the membrane or RF. The efficiency of the process is affected by the velocity, volume and duration of the RF. RF is generated by either water alone, water with oxidants, acids or water with compressed air (air



The Pall Aria AP system is packaged and suitable for smaller communities.



The same tough membrane technology is available in budget-friendly packaged or custom Pall Aria systems for communities of all sizes.

scrubbing). In both the air and liquid backwash, water will dislodge the fouling material. The sheer force at the membrane surface is greater during air scrubbing as it increases the velocity of water on the membrane surface. The duration of the RF in air scrub is usually short. Dislodged material can be flushed from the module with feedwater. Oxidants are sometimes added to the RF water to enhance the efficiency of the liquid backwash. Strong oxidants, such as free chlorine and chlorine dioxide can disrupt the structure of the fouling material and facilitate its removal. Alternatively, the recirculation of small air bubbles on the membrane surface can scour and disrupt the fouling material mechanically.

Chemical cleaning

RF and air scrub provide a short-term strategy for removing fouling materials. Although an effective RF/air scrubbing strategy will retard the rate of membrane fouling, eventually the membrane must be chemically cleaned to restore its TMP. The typical duration between chemical cleanings is four to six weeks. Cleaning protocols for MF membranes vary according to the membrane tolerance to cleaning chemicals. In general, a low pH solution (pH of two to three) removes cationic species and a high pH solution (pH 11-12) removes organic material. The action of the caustic cleaning solutions can be enhanced by the addition of non-ionic surfactants (provided the surfactant can be rinsed to meet regulatory requirements), which help to disperse the organic particles without binding to the membranes and chelating agents and are particularly useful for the disruption of cationic polymer bridging in biologically fouled membranes. Chlorine dioxide, free chlorine or peracetic acid can be used with synthetic polymer membranes, which are resistant to strong oxidants.

System recovery

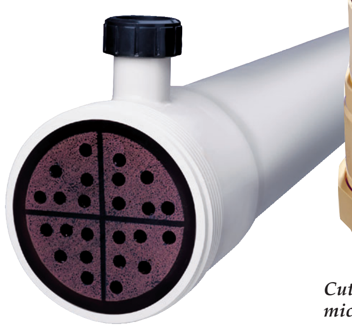
Recovery is defined as the ratio of the volume of product water (permeate) produced to raw water treated. Even though MF systems are typically operated in a dead-end mode, a portion of the permeate is used in steps to keep the membrane clean. The MF process recovery is a function of the permeate flow rate, the length of the filtration cycle and the volume of water used in a backwash. For surface waters, the filtration cycle is usually 20 to 30 minutes, with a process recovery of 95 to 97 percent.

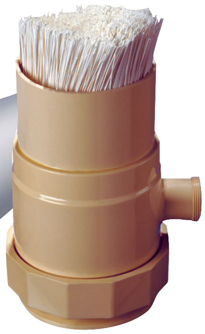
Filtrate quality assurance monitoring

If intact, a membrane offers essentially 100 percent removal efficiency for targeted microbial pathogens. If the membrane is not integral and depending upon the number of fibers compromised, microbial contaminants will pass through the membrane. Therefore, it is important to know if a compromise to the membrane has occurred. Several direct and indirect integrity methods are currently available, including the air pressure hold test, bubble point determination, online particle monitoring and online turbidity monitoring.

Monitoring of system integrity can either be performed online (during filtration) or offline (filtration is stopped). The online tests are based on light scattering methods and include particle monitoring (which counts the number of particles in the permeate) and particle counting (which determines both the number and size). New inline/online techniques such as anodic stripping voltammetry for oxidation-reduction potential (ORP) markers, glucose monitoring amperometric electrodes and rapid analysis of sensor arrays are under development. Offline tests are based on the measurement of the rate of decay of static air pressure across the MF membrane. This pressure will slowly decrease as the air diffuses into the water. Any holes or imperfections in the membrane will permit the much greater flow of air through the membrane. This is easily detected by an increase in the rate of decay of the static pressure. The type and frequency of the membrane in-

View of the lower end of a microfiltration (MF) module for a membrane water treatment system.





Cutaway view of a microfiltration (MF) module for a membrane water treatment system.

tegrity test will vary depending on the application and the attitudes of the local regulatory body.

One way to ensure the quality of the MF system permeate and the removal of bacteria such as *Cryptosporidium* is to use a disposable, one-micron rated membrane cartridge filter following the MF system. The high quality of MF permeate ensures a long life for the high-dirt capacity cartridge filter and offers an affordable quality assurance mechanism that requires minimal attention. Rapid plugging of the cartridge filter indicates a breach in MF membrane integrity.

Other regulatory standards

In addition to the requirements of the *LT2 SWTR*, small communities will eventually have to meet new maximum contaminant levels (MCLs) for DBPs. Consequently, these communities will be required to meet more stringent disinfection requirements while decreasing the use of chemical disinfectants. Both these apparently conflicting objectives can be achieved using MF membranes. The ability of MF membranes to provide a high level of disinfection without the use of chlorine as a primary disinfectant lowers the potential of DBP formation.

Summary

MF membrane systems provide small communities with a cost-effective design alternative that complies with the requirements of the SWTR and DBP regulations. Small flexible system footprints, operator friendly interface and maintenance, small increment expansion capabilities allow small communities to meet today's requirements and tomorrow's challenges.

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About the company

♦ *Pall Corporation is a global leader in the rapidly growing field of filtration, separation and purification. Pall is organized into two businesses: Life Sciences and Industrial that provide leading-edge products to meet the demanding needs of customers in biotechnology, pharmaceutical, transfusion medicine, energy, electronics, municipal and industrial water purification, aerospace, transportation and broad industrial markets. Total revenues for fiscal year 2006 were $2.0 billion. The company headquarters is in East Hills, NY with extensive operations throughout the world. For more information visit Pall at www.pall.com.*

About the technology

♦ *Pall Aria™ water treatment systems are designed to produce drinking water that meets today's stringent standards. More than 150 systems have been installed around the world to serve communities and businesses of all sizes. Pall Aria™ Membrane Water Treatment Systems use uniquely designed filtration modules in a hollow-fiber configuration to remove the following contaminants from surface and groundwater sources: suspended solids/turbidity; viruses; bacteria; cysts and oocysts; iron and manganese; arsenic and organics. The tough, hollow-fiber membranes are highly permeable, resulting in high water production rates. Each module provides an active surface area of up to 538 ft². Pall's dedication to a simplified process and control design has produced a family of systems that are characterized by: operator-friendly controls; simple surface water treatment without coagulation; unique air scrub and flush operation; high efficiency, low waste; excellent compatibility with chlorine and common treatment chemicals; long service life and minimal cost of operation; easy installation using modular skids and compact system footprint.*