https://doi.org/10.1002/opfl.1292

Scott Freeman is the owner of Membrane Medic, Madison, Wis. He can be contacted at membranemedic@gmail.com.

Although a relatively new technology, membrane systems are widely used for water filtration. To save money and increase reliability, take a proactive approach to membrane system operations by understanding the basics, following recommendations, and using updated design concepts. BY SCOTT FREEMAN

IMPROVE MEMBRANE SYSTEM PERFORMANCE AND REDUCE COSTS

MICROFILTRATION AND ultrafiltration (MF/UF) membranes provide excellent filtration for hundreds of water utilities, with high log removal of *Giardia* and *Cryptosporidium* as well as low product water turbidity. Since the introduction of MF/UF installations in the early 1990s, they have become larger and more complex, integrating membrane treatment with conventional processes. Initially, plant capacities were generally less than 5 mgd, according to AWWA's Manual of Water Supply Practices M53, *Microfiltration and Ultrafiltration Membranes for Drinking Water*. However, plants in the 20- to 50-mgd range became relatively common during the first decade of widespread use, and some utilities operate membrane facilities on the order of 100 mgd.

During the first few years of municipal-scale MF/UF history, membranes were generally applied with minimal pretreatment (typically with only a protective prescreen, which is a basic requirement for this technology). Now, integrating pretreatment with membranes has become commonplace. Examples of pretreatment operations that are integrated with MF/UF include oxidation of iron or manganese or both as well as coagulation-flocculation and sometimes sedimentation to help remove dissolved contaminants.

With a new technology such as MF/UF, there are plenty of opportunities for design and operational improvements. Here, I provide a few suggestions based on my three-plus decades of experience with a wide range of membrane types.

PHOTOGRAPH: SUNDRY PHOTOGRAPHY, SHUTTERSTOCK.COM

If operators take proactive steps, such as conducting regularly scheduled preventive measures, they're likely to have more reliable MF/UF facilities, with lower operating costs, than if they instead react to problems as they arise.

DE-RATE PILOTED FLUX

All technologies have potential problems. A key issue for MF/UF is the risk of fouling, which increases operating costs and, in more extreme cases, prevents plants from consistently operating at maximum capacity. With conventional granular media filters, there's a greater risk of not meeting finished water quality goals (such as turbidity breakthrough) than of experiencing reduced capacity. With MF/UF, these risks are reversed.

According to M53, membrane filtrate turbidity is 0.1 ntu or less essentially all the time, "regardless of influent turbidity … membrane type, manufacturer, or whether a coagulant was used," with pathogen removal of 4-log or higher (verified daily by a simple automated test). As a result, capacity shortfall is a greater risk, especially if flux is set too high. (Flux is filtrate flow per membrane area, a concept similar to hydraulic loading with granular media filters.)

A simple way to reduce such risk is to de-rate the piloted flux. Since the 1990s, I have observed fouling problems occurring at full-scale plants—even at flux levels that were successfully demonstrated during pilot studies. There are two possible causes. First, a full-scale plant treats a wider range of feedwater quality than a limited-duration pilot, so there's greater risk of a fouling event. Second, flow distribution at full scale is less ideal than during a pilot study. Some elements on a large rack may experience less-effective backwashing, leaving foulants behind. Knowing the root cause is less important than providing a margin of safety by de-rating flux with an "adjustment factor," as shown in the following equation:

Full-Scale Flux = *(Successfully Piloted Flux)* × (*Adjustment Factor* < 1)

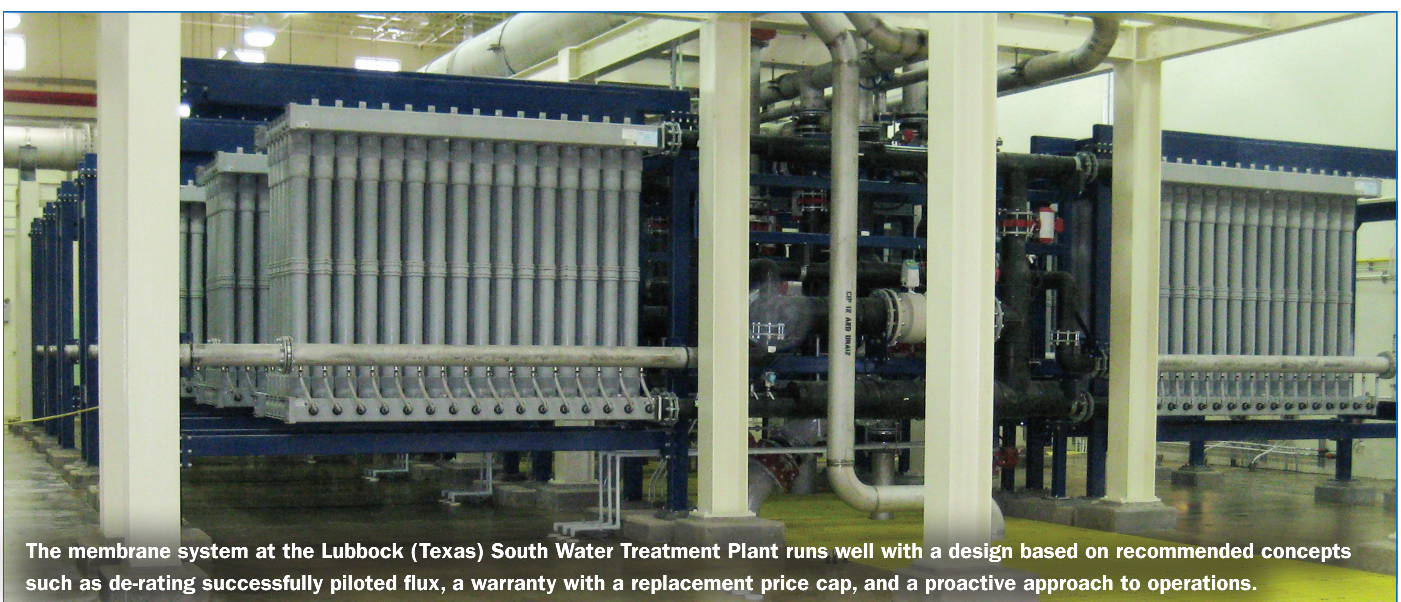
Generally, I have applied a factor of 0.8 or, in cases with little variation in feedwater quality or longer-duration pilot studies, 0.9. Discussions with other designers indicate this method is becoming more widely practiced.

REVIEW ANSI/AWWA STANDARD B112

In 2015, AWWA and the American National Standards Institute released ANSI/AWWA B112-15, a standard for MF/UF systems, with information for designers and operators. (A revision is pending that may be published in 2020, as standards of this type are typically revised every five years.) The standard addresses two topics summarized here: (1) reduce the number of terms to make operator training easier, and (2) calculate flow to more accurately determine net capacity.

Many membrane system manufacturers use different terms to describe the same things, which makes it challenging for operators to understand these systems. Inconsistent terminology also complicates training and the ability to compare treatment results with those of other utilities. For example, the preferred term *filtrate* is sometimes called *permeate*, which can be confused with *reverse osmosis permeate*; the preferred term *backwash* is sometimes called *backpulse* or *reverse filtration*; and the preferred term *clean in place* is sometimes called *recovery clean*, *flux maintenance*, or *extended clean*. This problem would be resolved if manufacturers' documentation and instruction manuals used only B112-preferred terms.

Another key issue for operators is calculating the available net daily membrane filtrate flow rate, or the plant's capacity. It seems like such calculations would be universally understood, but this is more complex than with conventional treatment, where capacity equals hydraulic loading multiplied by area. For



The membrane system at the Lubbock (Texas) South Water Treatment Plant runs well with a design based on recommended concepts such as de-rating successfully piloted flux, a warranty with a replacement price cap, and a proactive approach to operations.

PHOTOGRAPH: CITY OF LUBBOCK (TEXAS) WATER UTILITIES

With a new technology such as MF/UF, there are plenty of opportunities for design and operational improvements.

membranes, the format of the capacity equation depends on the control philosophy—i.e., duty unit or cycle rotation operating mode. It's definitely not just flux multiplied by membrane area. It's important to account for the downtime. Membrane trains don't produce filtrate about 13 percent of the day because of integrity testing and approximately 50 backwashes per day that reduce productive time and consume filtrate. Once again, the solution to the problem is easy: apply equations in the B112 standard.

CONSIDER FIBER BREAKAGE AND REPLACEMENT WARRANTIES

A 2012 research paper included a summary of fiber breakage at full-scale plants that indicated a weighted average frequency of 12 repair events per year per mgd of capacity (r-e/yr-mgd), with a projected annual cost of $830/yr-mgd. When the paper was presented at the 2012 American Membrane Technology Association/AWWA Membrane Technology Conference in Glendale, Ariz., audience members indicated the membrane industry should have a short-term goal of fewer than 10 r-e/yr-mgd, with a longer-term maximum of three events.

Even if the annual repair costs could be considered low compared with other operating costs (fiber repair costs were about 4 percent of total annual costs), operators and utility managers dislike the nuisance of fiber failures. I recommend including quantified warranty requirements in purchase documents to protect utilities from excessive repair costs.

A method presented at the 2019 Membrane Technology Conference in New Orleans proposes including warranty replacement if more than 0.1 percent of fibers in an element or up to 10 fibers/element require repair during the element's service life (typically defined as 10 years), whichever value is lower, or if an element requires repair more than three times in any three-month period or six in six months. All the elements in a unit would be replaced if more than 10 percent must be isolated and/or repaired (essentially a no-lemon clause to protect the utility from a bad batch). As an alternative to element replacements, a supplier could make all repairs to maintain each train above an agreed-to removal threshold (e.g., 4.2-log).

MF/UF suppliers tend to consider these proposed warranty limits too low and therefore too costly to guarantee. I recommend practitioners consider the potential risk to the utility for worst-case conditions. A seemingly low 10-year failure rate of 0.1 percent (equivalent to 10 in a 10,000-fiber element) could result in a 10-mgd WTP with about 350 to 500 elements having 350 to 500 repairs per year, or 35 to 50 r-e/yr-mgd, exceeding the short-term industry goal of 10 and resulting in costly risk for the utility.

As far as future replacements are concerned, all membrane-based WTPs will need to replace membranes someday as a result of increased rates of breakage as the membranes age and/or accumulated irreversible fouling. It helps utilities plan and control costs if the original purchase includes a maximum element price, generally with inflation adjustment over a 10- or 20-year period. This prevents utilities from being charged excessively high prices for replacement elements. This may become less of an issue in the future, as there's more competition from alternative suppliers; even so, it's simple to establish a future maximum price ceiling when purchasing the original system.

AVOID "STICKY" PRETREATMENT CHEMICALS

Many full-scale membrane-based WTPs apply coagulation–flocculation pretreatment to address dissolved materials that wouldn't be sufficiently removed by the membranes alone (e.g., disinfection byproduct precursors or taste-and-odor–causing compounds) or to remove fouling agents. It's a widely accepted practice not to include polymeric coagulant aides in MF/UF pretreatment, as these chemicals can be attracted to the membrane and frequently cause irreversible fouling. However, there are no widely accepted guidelines for which coagulants can be used without causing fouling, forcing designers and users to choose on their own.

Empirical observations indicate that alum and iron-based coagulants often aren't good choices for MF/UF. Multiple projects have been observed in which fouling problems were addressed by changing from alum or iron-based coagulants to types of polyaluminum chloride and aluminum chlorohydrate that have proven success with a specific MF/UF membrane. Consider jar testing coagulant options to determine applicability and operating conditions (such as dose, contact time, and pH adjustment) that will effectively remove the contaminants. For new projects, piloting with the specific type of coagulant and pretreatment is recommended; on-site testing is recommended for existing plants.

ENGINEER MORE THAN MEMBRANES

Discussions of membrane system engineering often focus only on the membranes and associated operating parameters (e.g., maximum sustainable flux, backwash frequency, fouling sources, and cleaning conditions). However, there are many other aspects regarding ancillary support equipment that can significantly affect the satisfaction of the utility's operators and managers.

In recent discussions with staff at six membrane WTPs, I was reminded of the importance of ancillary equipment, including prescreens, air compressors, actuators, and valves. As just one example, compressed air systems benefit from redundancy and oversizing (with air capacity exceeding membrane system requirements) so the utility can provide air to other parts of the facility without limiting membrane operations.

IMPLEMENT PROACTIVE OPERATIONS

Consider two types of projects. In one, the facility design, equipment, and installation are close to perfect, but operator training is minimal. For the other project, the operator training program is excellent, but the installation is average. Which of these projects is more likely to perform well in the long term, with fewer problems and lower overall costs? It's definitely the one with excellent operator training.

M53 details operator training and troubleshooting, and the following bullet points summarize some useful concepts:

- **Collect early setpoints and results.** When a facility is relatively new (roughly two to six weeks after startup) and running well, collect a full set of performance results and setpoint values, including printouts of all operating screens. Additional sets should be collected every six months. By comparing data with the initially successful conditions, this information will be useful if and when troubleshooting is needed.
- **Conduct simple membrane math.** Because MF/UF membrane plants are monitored by a programmable logic controller, some operators think a computer is operating the plant and people don't need to know how to calculate parameters (e.g., flux, transmembrane pressure, and temperature-corrected permeability). However, it's beneficial for operators to also conduct such calculations to check on the automated control and to develop a better understanding of the plant and important concepts for long service life and lower operating costs.
- **Understand temperature correction.** If operators don't understand temperature correction, they may think a membrane is clean when it's not, which can result in a failure to conduct cleaning when needed or not understanding whether a cleaning has been successful. To make temperature correction easier for operators, instructions and forms can include a table of temperature correction factors. A simplified hand calculation may not agree to the decimal place with a more complex computer-applied formula, but it will be close enough.


Even a minute percentage of membrane fiber breaks can necessitate significant membrane repair.

- **Don't delay clean-in-place (CIP) cycles.** Sometimes operators, especially those new to membranes, delay cleaning when the membrane equipment is new. Unfortunately, the problem may not be discovered until after the membrane is irreversibly fouled. It's better to clean at regular intervals (e.g., monthly) at least until there are 12 months of site-specific results on which to base decisions. In addition, CIP is also periodically conducted as indicated by performance (e.g., temperature-corrected permeability).
- **Collect and evaluate CIP results.** Utilities should collect performance data (e.g., temperature-corrected permeability, water temperature, flows and pressures, feedwater quality, and turbidity) a few hours before and after every CIP as well as descriptions of CIP conditions (e.g., chemical dose, soak times, flow conditions, and duration of each step). At first it may seem excessive to record and archive this information, but over the life of the facility, these parameters may get changed (sometimes unintentionally), and understanding past practices can help future users troubleshoot problems.
- **Verify maintenance wash (MW) dosing.** A classic problem with MW is underdosing of chemicals. This could be attributed to an unwanted shift in valve timing, inaccurate calibration of a chemical feed pump, and/or a decline in the concentration in the stock solution. One common problem is underdosing of hypochlorite during MW. A regular preventive maintenance program helps utilities avoid this and many other problems.

ADDITIONAL SUGGESTIONS

If operators take proactive steps, such as conducting regularly scheduled preventive measures, they're likely to have more reliable facilities, with lower operating costs, than if they instead react to problems as they arise. For additional suggestions, operators should consult M53 and the operations and maintenance manual for their specific systems as well as hold discussions with other utilities to learn about their methods. Also, several membrane system suppliers have user groups to encourage the sharing of ideas. These groups could provide a significant source of information for operators.

PHOTOGRAPH: RACINE (WIS.) WATER UTILITY