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Membrane Treatment: Operators Need to Understand Critical Concepts

The number of potable reuse projects in the United States has increased the need for operators who are knowledgeable about advanced water treatment processes, including membrane treatment technologies.

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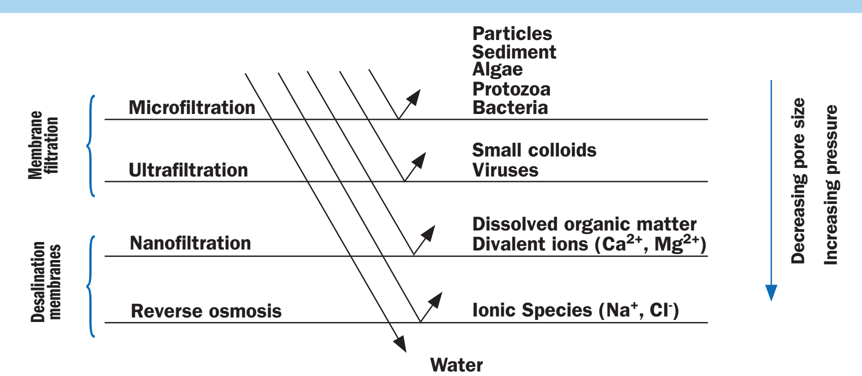
TO HELP MEET the need for operators who are knowledgeable about processes included in advanced water treatment trains, an operator training program was developed by Pure Water San Diego, a phased, multiyear project that will provide one-third of San Diego's water supply locally by 2035. Pure Water San Diego will use proven water purification technology to clean recycled water to produce safe, high-quality drinking water.

Many of Pure Water San Diego's trainees will be tasked with starting and operating the North City Pure Water Facility (NCPWF), which will treat and purify wastewater to supplement the city's drinking water supply using surface water augmentation. Once operational, the new plant will target a production capacity of 34 mgd. To give operators firsthand experience with the types of advanced treatment processes that will be used at NCPWF, operators are currently being trained in San Diego's 1-mgd Pure Water Demonstration Facility (PWDF), which uses the same treatment processes as the future full-scale facility and consists of ozone, biological activated carbon, parallel microfiltration/ultrafiltration (MF/UF) and reverse osmosis (RO) membranes as well as an advanced oxidation process using ultraviolet light and hypochlorous acid. San Diego's approach to operator training includes hands-on training, classroom lectures, and tests. To help operators run today's advanced water treatment trains, Pure Water San Diego's training program stresses the following concepts related to membrane filtration operations, maintenance, and compliance.

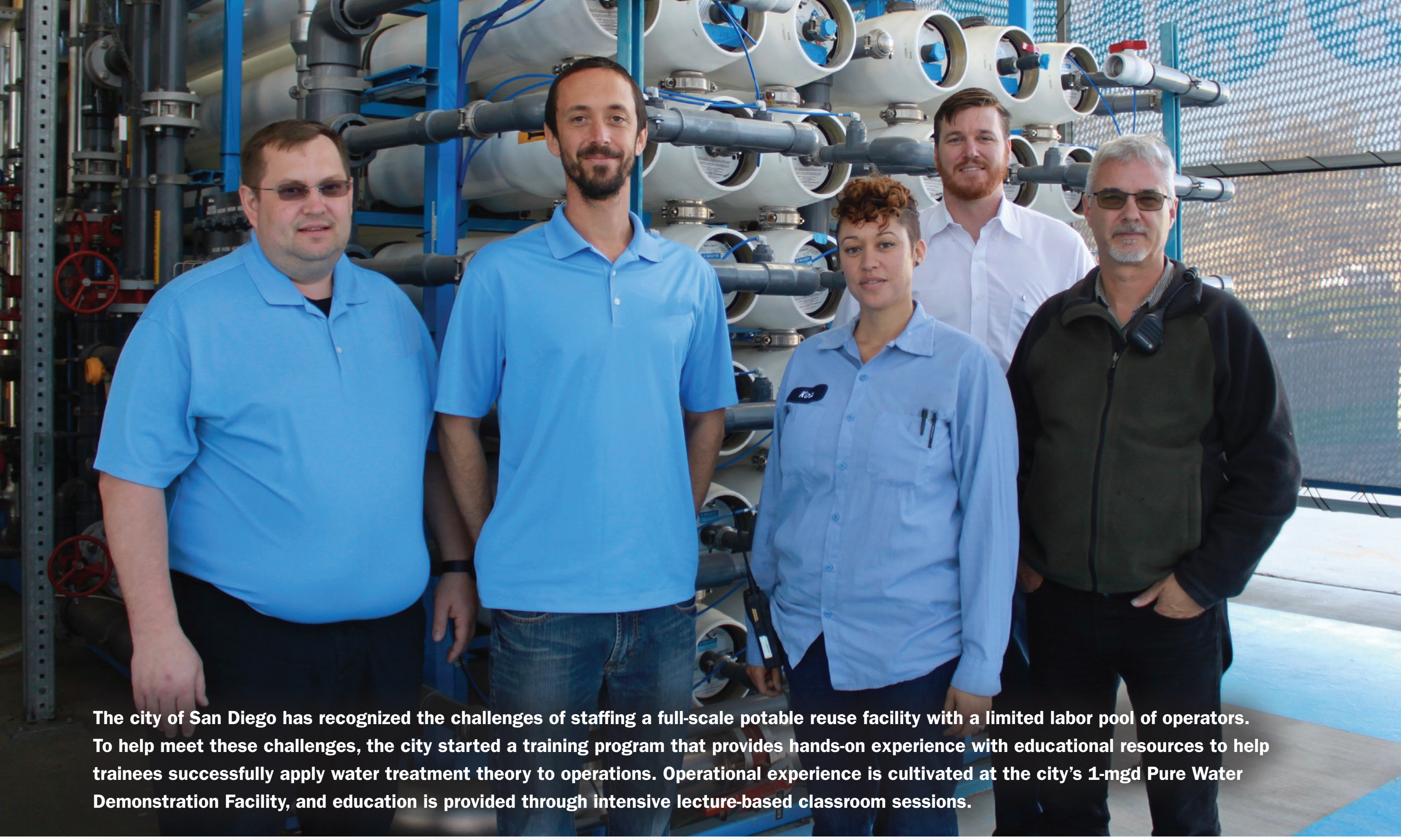
Membrane Types

Water utilities use membranes to address a variety of treatment challenges.



MF/UF TREATMENT

Treatment Theory. MF and UF membranes are typically made of a semipermeable synthetic material. Most MF/UF membranes are fabricated from polymeric materials that are extruded into hollow fibers with a diameter of less than 1 mm. Although many different base polymers have been used during the last decade, most new membranes are composed of polyvinylidene fluoride or polyethersulfone. Both materials provide strong, permeable, and chemically tolerant membranes. Generally, thousands of membrane hollow fibers are bound together to make a membrane module. Depending on the target capacity of each



The city of San Diego has recognized the challenges of staffing a full-scale potable reuse facility with a limited labor pool of operators. To help meet these challenges, the city started a training program that provides hands-on experience with educational resources to help trainees successfully apply water treatment theory to operations. Operational experience is cultivated at the city's 1-mgd Pure Water Demonstration Facility, and education is provided through intensive lecture-based classroom sessions.

membrane train, membrane modules are grouped together within a membrane rack to make a membrane train.

Membrane filtration systems are configured as either submerged or encased systems. In submerged systems, the membrane modules are manifolded together and suspended within a feedwater tank. A filtrate pump creates a suction force (i.e., negative pressure) that pulls the feedwater through the membrane pores to filtrate-collection piping. In encased systems, the membrane modules are housed within skid-mounted pressure vessels. A filtrate pump, located upstream of the membrane system, creates pressure that drives the water through the membrane pores to filtrate-collection piping.

The passage of components through a membrane is governed mainly by pore size. Commercially available MF membranes have a nominal pore size of approximately 0.1 microns, whereas UF membranes have typical pore sizes in the range of 0.01 to 0.04 microns. These pores are one to two orders of magnitude smaller than key waterborne pathogens such as *Cryptosporidium* and *Giardia*, bringing about near-absolute removal of these pathogens. In general, membranes with smaller pore sizes require higher pressure to operate.

MF and UF systems employ dead-end filtration, which means all feedwater is filtered through the membrane. Other membrane technologies may use cross-flow filtration in which a fraction of the feed flow is filtered and captured as permeate. In dead-end filtration, process water may enter either through the outside of the membrane (outside in) or may be diverted to the inside of the membrane (inside out). The passage of water through the membrane surface acts as a barrier against solids and particles, as they can't pass through the membrane's pores.

Applications. Membrane filtration systems can be used in place of conventional media filtration in a range of different applications, including direct filtration of surface water, filtration of clarified surface water, groundwater filtration, pretreatment for RO membranes, and wastewater filtration. Both UF and MF membranes can provide protozoa removal beyond 4.0 log, which is confirmed with daily membrane integrity tests that can detect fiber breakages in a membrane skid. Integrity is also confirmed indirectly by monitoring the filtrate turbidity. An increase in filtrate turbidity is an indicator of broken membrane fibers. Although MF and UF membranes also remove some viruses, no pathogen credit is given by the regulatory agencies.

Fouling and Scaling. Membrane operations is often a balancing act between

MF/UF modules (left) typically are arranged in a hollow-fiber configuration, whereas RO/NF membranes (right) use a spiral-wound configuration.

PHOTOGRAPHS: CITY OF SAN DIEGO

maximizing water production and minimizing fouling—the buildup of inorganic, organic, or biological matter on the membrane surface that effectively “plugs” the membranes. Automated backwashes are typically triggered by a timer and are able to at least partially remove buildup on the membrane. However, backwashes aren’t sufficient for delaying fouling indefinitely. Chloramines are also often used to control biological fouling of MF and UF membranes.

Changes to operational parameters are observed as fouling becomes more widespread on a membrane’s surface. Transmembrane pressure (TMP) is a typical operational parameter used for tracking membrane fouling. When fouling occurs, the TMP will increase. This indicates that greater pressures are required to filter the process water. Another parameter used for tracking fouling and related to TMP is permeability (also known as specific flux). Permeability is the production of water for a given driving pressure.

These parameters must be tracked carefully because allowing excessive foulants to build up may lead to irreversible fouling that permanently affects system permeability. Once fouling causes a significant increase in the TMP, a chemical cleaning such as a chemically enhanced backwash (CEB) or a clean-in-place (CIP) procedure may be performed to recover system pressures and permeability. In comparison to CEBs, which may be performed frequently and use a lower chemical concentration, CIPs are more extensive, using a longer recirculation and soak time as well as much higher chemical concentrations. Depending on the application and feedwater quality, CIPs may be performed monthly to annually. Different cleaning solutions are used for inorganic versus organic and biological foulants. Typically, citric acid is used to target inorganic foulants, and a bleach/caustic solution is used to target organic and biological foulants.

RO TREATMENT

Treatment Theory. RO is a membrane technology that effectively rejects ions, dissolved salts, and soluble-phase molecules from water. Nanofiltration (NF) is an RO technology that exhibits less efficient salinity rejection, particularly for monovalent ions. As a result of this lesser rejection, NF systems typically operate at lower pressures than those using RO membranes.

Membrane desalination is used for drinking water production when the source water is brackish groundwater or seawater. Under osmosis, water moves across a semipermeable membrane from an area of low-solute concentration to an area of high-solute concentration. In RO, pressure is applied to one side of the membrane to overcome the osmotic pressure. This allows water to pass through the membrane while solutes are retained on the pressurized side of the membrane.

Although typical membrane filtration systems operate at pressures up to 40 psi, membrane desalination systems can run much higher. For RO, the feed pressure is based on overcoming the inherent pressure losses throughout the system and on the osmotic pressure of the water being treated. More saline feedwater has higher osmotic pressure, which in turn increases the feed pressure required to drive water through the membrane. For brackish water (1,000 to 10,000 mg/L of total dissolved solids), RO systems typically operate at 100 to 300 psi, depending on the type and age of the membrane. For seawater (30,000 to 40,000 mg/L of total dissolved solids), the operating pressure could be as high as 800 to 1,200 psi.

RO membranes are thin-film composite membranes that include an active layer and other layers cast on top of one another during manufacturing. The separation of water and solutes takes place at the active layer, and other layers support the thin active layer. Advancements in RO membrane technology continue to decrease the energy footprint and associated operating costs, improve rejection of dissolved constituents, and prolong membrane operating life.

RO operates in a cross-flow configuration. Feedwater flows parallel to the membrane and passes through the membrane. A portion of the flow remains on the pressurized feed side and is released at the end of the membrane vessel. Recovery is the fraction of feedwater filtered into clean water. The water that passes through the membrane is called the *permeate*, and the water that remains on the feed side is called the *concentrate*. The permeate is relatively free of solutes, as the membrane acts as a barrier for the solutes. Because the solutes remain on the pressurized side,

Common MF/UF filtration system components include (from left) a skid, a CIP system, and a compressed air system.

PHOTOGRAPHS: CITY OF SAN DIEGO

Understanding treatment theory and being able to apply the knowledge during daily operations are key objectives when training operators new to membrane operations.

Common RO filtration system components include (from left) a skid, feed pumps, and a permeate flush pump.

they become concentrated as more water passes through the membrane.

Most RO systems share a common design and components approach. Each system must have a feed pump that can produce the flow rate and pressure required based on the water quality being processed. The flow rate is often set and maintained using a flowmeter that controls a variable-frequency drive for the feed pump. In such a scenario, the amount of water recovered through the membrane as permeate is controlled by a concentrate control valve (CCV). The more the CCV closes, the more water diffuses through the membrane and is recovered as permeate. The term *recovery* is the percentage of the feed flow recovered as permeate.

Full-scale systems in the water and wastewater industry are typically composed of hundreds of membrane elements. Most full-scale municipal systems use 8-in.-diameter membrane elements. Elements are put together into pressure vessels that typically hold six to eight elements in series. The vessels are either fiberglass-reinforced plastic or stainless steel, depending on application and pressure requirements. Multiple vessels are piped together in parallel, forming a stage. The concentrate from one stage may be treated further by additional stages to increase the overall system recovery and reduce the leftover concentrate water that must go to drain for disposal or further treatment. Two- to three-stage systems are common for typical municipal applications to achieve 75 to 85 percent recovery.

Feedwater must first be prefiltered before it is introduced to the RO system to avoid membrane damage. MF/UF membranes or cartridge filters may be used. Permeate from the RO is typically low in alkalinity and hardness and will corrode downstream equipment. Permeate posttreatment typically involves removing dissolved gases and adjusting alkalinity and pH. Concentrate (brine in saline water applications) is generated when using RO, and proper disposal and handling of concentrate streams must be considered.

Applications. RO is used in many groundwater treatment and potable water reuse applications because of its ability to remove many contaminants and reduce salts in the water. Secondary or tertiary effluent from municipal wastewater treatment plants that otherwise would be discharged to the environment can be reclaimed and either offset or augment potable water supplies for multiple end uses. For potable water reuse applications, the inclusion of RO in groundwater recharge and surface water augmentation applications is currently required by the state of California. RO permeate must demonstrate <0.5 ppm as total organic carbon (TOC) for potable water reuse applications. RO systems may also be credited with pathogen removal. TOC and electrical conductivity removal are common surrogates for evaluating pathogen log removal credit through the RO system.

Fouling and Scaling. Chemicals are added to the RO feed to control scaling and fouling. Chemicals added to feedwater typically include an antiscalant agent for scale prevention, sulfuric acid for pH adjustment to increase solubility of potential precipitates such as calcium carbonate and calcium phosphate, and chloramines for controlling biological fouling.

As with MF/UF membrane filtration, changes to operational parameters are observed as fouling becomes more widespread. The net driving pressure (NDP) is a typical operational parameter used for tracking RO membrane fouling. When fouling occurs, NDP will increase. This indicates that greater pressures are required to filter the process water. Another parameter used for tracking fouling and related to NDP is the permeability (specific flux).

Once fouling is detected, a CIP may be performed to recover membrane permeability and system performance. Typically, a low pH solution is used to target inorganic foulants, and a high pH solution is used to target organic and biological foulants.

KEYS TO SUCCESS

Careful tracking of MF/UF and RO operations and maintenance is critical to successfully implement these treatment technologies. Understanding the nuances specific to membrane operations is vital to prevent membrane damage and to meet all treatment objectives. Understanding treatment theory and being able to apply the knowledge during daily operations are key objectives when training operators new to membrane operations.