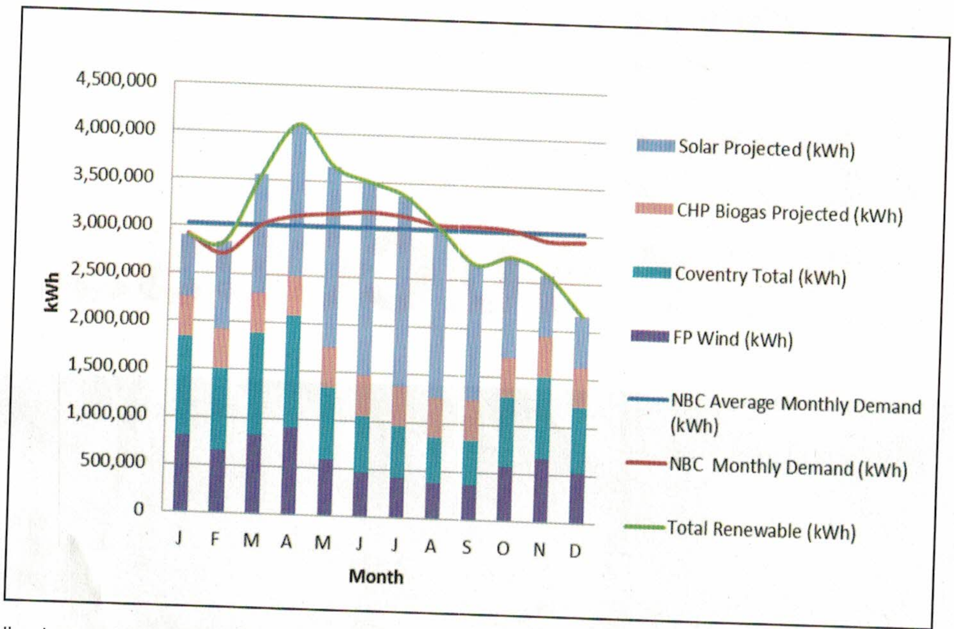
Seven keys to membrane bioreactor success

Figure 2. Predicted renewable energy production by month relative to NBC demand



line losses. However, available renewable energy resources and available land area limits options for behind the meter systems. To obtain its remaining electrical energy needs from renewable resources, NBC needed to look to off-site generation.

Coventry wind project. In 2014, Rhode Island passed legislation that, in part, allowed for the net metering of renewable electricity. This allowed NBC to purchase and operate three 1.5-MW wind turbines located within the rural community of Coventry R.I., about 32 km (20 mi) from NBC's various facilities. These turbines are part of a larger wind farm consisting of 10 wind turbines built by a local wind energy developer.

The renewable electricity produced at these wind turbines is metered by the local electric distribution company, National Grid, as it enters the local grid. Each kWh of renewable energy produced by these wind turbines shows up as a Renewable Net Metering Credit (RNMC) on specified NBC billing accounts with National Grid. The RNMCs are equal to the dollar value of the kWh of electricity generated during a particular billing period. NBC's three Coventry wind turbines became fully operational in October 2016.

The combination of these three NBC-owned and -operated renewable energy projects are capable of supplying about 60% of NBC's total 36,000,000 kWh/yr electricity needs.

Solar project. The NBC solicited proposals from solar energy developers to provide the remaining 40% of NBC's energy needs through a solar energy renewable net metering credit agreement (RNMCA), also known as a Power Purchase Agreement (PPA). The NBC selected a local renewable energy development firm to provide solar energy, and entered a PPA to obtain solar energy from three sites in southern Rhode Island. Two sites became operational in mid-2018. The third site was delayed due to local town permitting issues and is scheduled to be replaced by an alternate renewable energy source in early 2019.

Figure 2 (left) shows a graphical analysis of the predicted monthly renewable energy generation relative to NBC's overall demand. In months where generation exceeds demand, the net metered credits will be carried forward to balance out the months where generation falls short of demand.

Table 4 (below) shows the economic summary of all of NBC's renewable energy programs. It should be noted that the economics of both the Coventry wind and Solar RNMCA projects rely strongly on the value of the RNMCs received. However, the bottom line is that cost of this electricity, if purchased from the grid, would be $3,960,000 per year. This means NBC saves more than $1.56 million annually by seeking out sustainable, renewable energy.

The energy demands and needs of WRRFs are constantly changing due to stricter regulatory requirements, weather conditions, new technologies, etc. NBC recognizes these changes and has committed itself to achieving and maintaining 100% renewables through continuingly assessing energy needs and additional renewable energy resources, and fully utilizing all available cost-effective energy efficiency and conservation opportunities.

James McCaughey *is director of administration,* ***Thomas Uva*** *is director of environmental science and compliance,* ***Barry Wenskowicz*** *is sustainability engineer, and* ***Kerri Houghton*** *is environmental compliance technical assistant at the Narragansett Bay Commission (Providence, R.I.).*

Table 4. Economic summary of NBC renewable energy projects

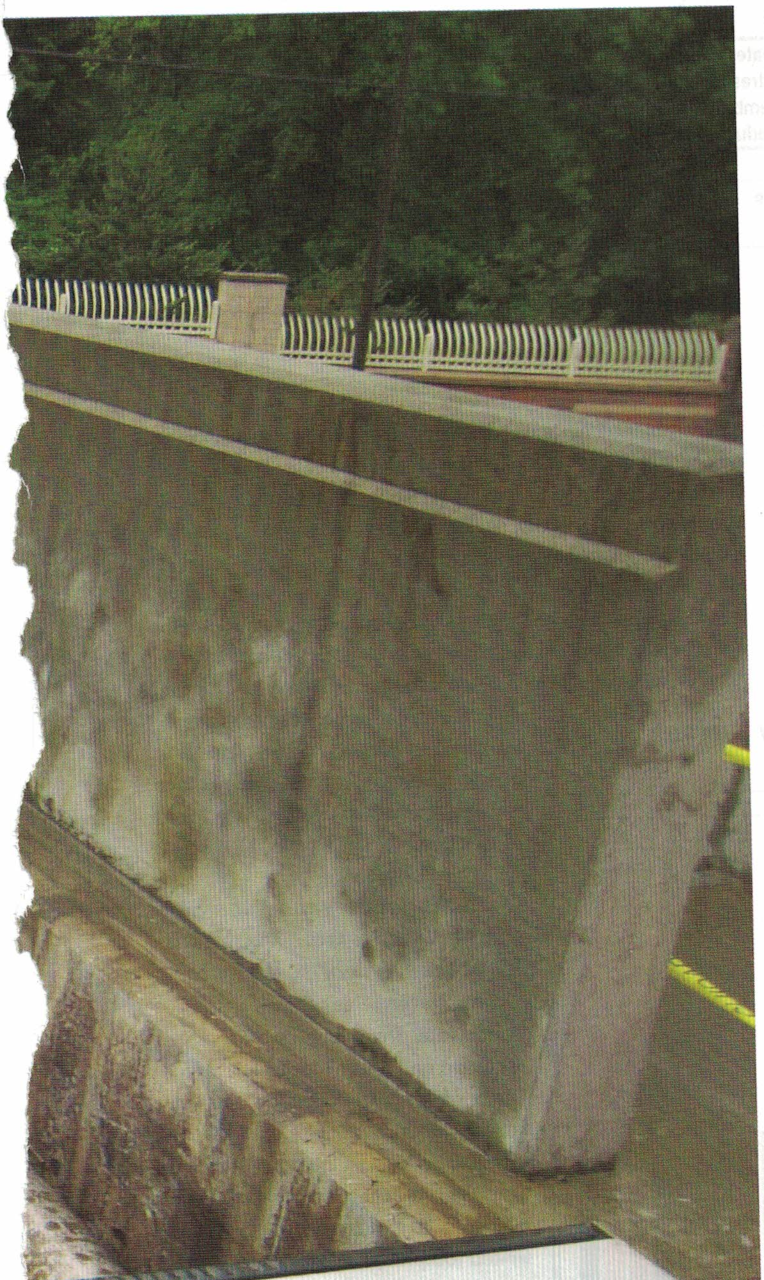
Renewable energy project	Capital cost	Annual operating cost	Estimated annual production (kWh)	Cost ($/kWh)	Cost w/ REC ($/kWh)	Net cost ($/year)	Cost if purchased from grid ($/year)	Cost savings ($/year)
Field's Point wind	$12,923,680	$162,027	7,806,587	$0.09	$0.07	$522,842	$858,725	$335,883
Coventry wind	$18,000,000	$295,551	9,421,649	$0.11	$0.09	$827,118	$1,036,381	$209,263
Bucklin Point biogas	$6,188,000	$104,510	4,467,728	$0.08	$0.06	$262,676	$491,450	$228,774
Solar	–	–	14,304,036	$0.08	$0.06	$786,722	$1,573,444	$786,722
Total	$37,111,680	$562,088	36,000,000			$2,399,358	$3,960,000	$1,560,642

Assumptions include 25-year project life, $0.11/kWh for grid-purchased electricity, NMC-value of $0.14/kWh, and REC-value of $0.020/kWh. The analysis does not consider the cost of capital financing or inflation over the project life.

Designers and operators have discovered these keys based on 15 years of progressive MBR experience in the Pacific Northwest

of

Patrick Roe



One of the seven keys to success with membrane bioreactors is to plan for facility maintenance. At the Picnic Point Wastewater Treatment Facility in Edmonds, Wash., narrow spacing between the membrane cassettes and tank walls minimize footprint, but also make the annual cleaning process a challenge.

The first generation of membrane bioreactors (MBRs) in the Pacific Northwest arrived around 2003. This new technology represents a considerable advancement over conventional wastewater treatment, particularly the ability to produce a high-quality reclaimed water product within a small physical footprint. As with any new technology, the past 15 years has led to many lessons that can be applied to design and operation. Manufacturers also are continuing to refine membrane technology and develop new products.

During the past 15 years, seven topics have emerged as critical concerns to consider when working with MBRs. The guidance is intended toward modifying existing membrane bioreactors to improve performance and operability, as well as to provide guidance for design and operation of new membrane facilities. These topics are based on case studies, evaluations, and modifications at four MBR facilities. The facilities include

- LOTT Clean Water Alliance, Martin Way Reclaimed Water Plant;
- Alderwood Water & Wastewater District, Picnic Point Wastewater Treatment Facility;
- Stevens Pass Sewer District, Wastewater Treatment Plant; and
- City of Coeur d'Alene Wastewater Treatment Plant.

No. 1: Initial membrane selection and design

Designers need to select carefully the membrane flux rate. It is recommended that pilot or demonstration testing be conducted prior to implementation of the full-scale facility. Membrane warranties typically dictate the conditions under which the membrane can be operated. While MBRs permit the use of high mixed liquor suspended solids concentration, there are limits.

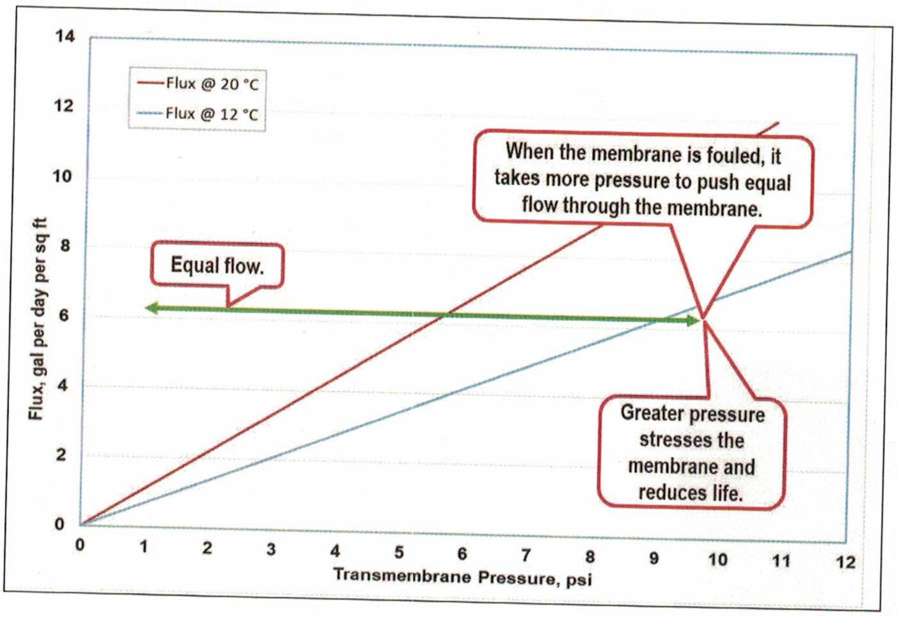
Key design membrane parameters are flux, defined as the flow divided by the membrane surface area, and transmembrane pressure (TMP), which is the pressure drop across the membrane surface area. Flux and transmembrane pressure are related, as shown in Figure 1 (p. 38), in that higher TMP will promote higher flux rates, but risks potential damage to the membranes. The slope of flux plotted against TMP is referred to as permeability. As membranes foul, permeability decreases, and greater pressure is required to pass the flow through the membrane.

A major design objective is to find the right balance between membrane flux and transmembrane pressure. Complicating the challenge is that wastewater flow is inherently variable due to the diurnal nature of human behavior, and collection system infiltration and inflow contributes to flow increases.

Selection of an appropriate flux rate is, therefore, a critical design decision. Selection of too high of a design flux rate may result in inadequate capacity, but selection of a low value may result in the installation of unnecessary capacity, at increased cost. Pilot or demonstration testing is desirable to confirm actual capacity and to help operators become familiar with the process. While full-scale data from similar operating facilities also can be used for design, demonstration testing removes uncertainties regarding the capability of membranes to treat the specific wastewater.

Vendors typically require a membrane warranty that limits the

Figure 1. Relationship between membrane flux and transmembrane pressure



city elected to construct a 0.8-ML/d (0.2-mgd) demonstration facility and operate it for 2 years to better understand required design parameters and familiarize the operators with the process. Flux information gathered during demonstration testing was used to design the full-scale facility as well as to negotiate warranty terms with the membrane supplier.

Recommendations

Owners considering implementation of membrane bioreactor facilities should carefully evaluate membrane flux during design. Pilot or demonstration testing is recommended to verify flux rates. In the 2018 paper, "Membrane bioreactors – lessons learned," authored by Gordon Culp and presented at the 2018 Nevada Water Environment Federation Association Conference, Culp recommends visiting installations that are operating the membrane type an owner is considering using.

service conditions. The warranty usually includes restrictions related to the maximum flux and transmembrane pressure that apply to the membranes, as well as the frequency and duration of these events. Any occurrence that exceeds the warranty values typically invalidates the warranty. Therefore, warranty terms must be reviewed during initial membrane procurement, and the design based on the requirements.

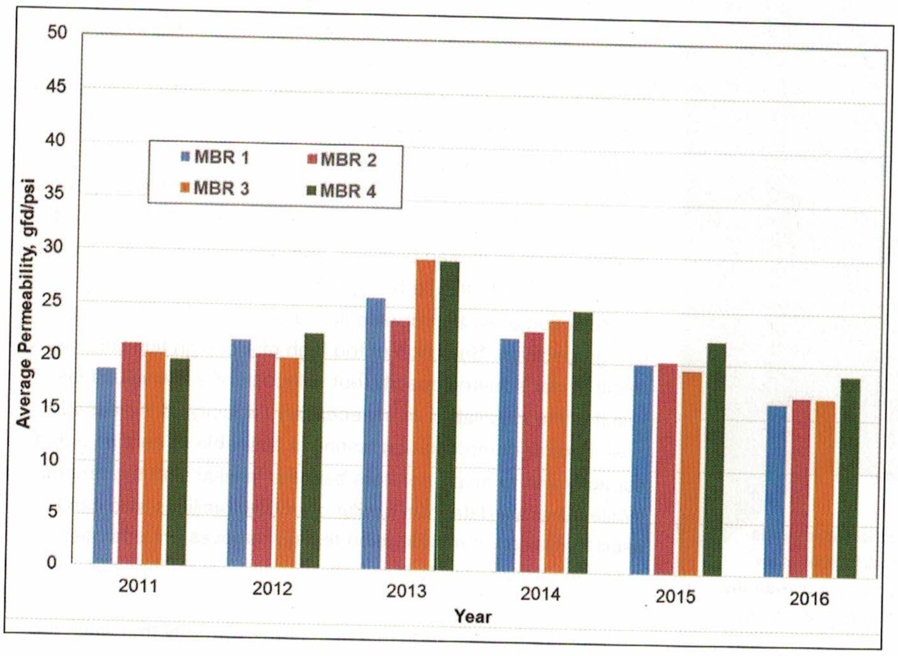
Case study: City of Coeur d'Alene (Idaho) Wastewater Treatment Plant

The city evaluated the feasibility of constructing a tertiary membrane facility to meet stringent effluent phosphorus limits as low as 50 μg/L. Rather than constructing full capacity initially, the

No. 2: Peak flow control

Membranes perform best when operated at steady flow and relative constant flux rates. However, wastewater flow is inherently variable in response to customer habits. In addition, wet weather affects wastewater flow, through collection system infiltration and inflow, to create peak flow events that contribute to wastewater management challenges. Designers and owners need to plan for what happens when the peak flow cannot pass through the membranes. Many utilities have implemented or are considering flow equalization. Other utilities have the capability to divert high flow to alternative treatment facilities. Equalization is also a useful process management tool for improving nutrient removal and increasing reclaimed water production.

Figure 2. Picnic Point Wastewater Treatment Facility average membrane permeability

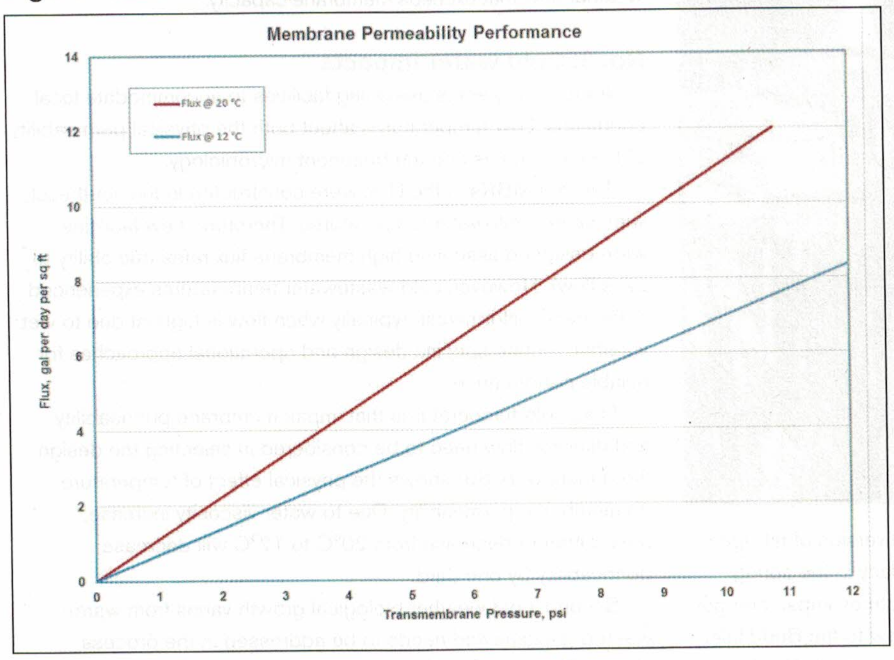


Case Study: Stevens Pass Sewer District Wastewater Treatment Plant (Leavenworth, Wash.)

The Stevens Pass Sewer District Wastewater Treatment Plant serves a ski resort and a small residential area. The original activated sludge treatment facility, with a capacity of 0.30 ML/d (80,000 gal/d) was located within a large building, protecting it from severe winter elements. To increase capacity within a limited footprint, the facility was converted to an MBR with a capacity of 0.81 ML/d (213,000 gal/d).

Since the major collection system customer is a ski resort, weekend visitors generate most of the weekly flow. The

Figure 3. Effect of temperature on membrane permeability



million gal) is required to attenuate peak flow events, based on sizing to comply with the membrane vendor's warranty requirements. Implementation is being programmed into the district's upcoming capital improvement program.

Case Study: LOTT Clean Water Alliance, Martin Way Water Reclamation Facility (Lacey, Wash.)

The LOTT Clean Water Alliance began operation of the Martin Way Reclaimed Water Plant in 2006. This satellite MBR facility was designed with an initial capacity of 7.6 ML/d (2.0 mgd), with the capability to be expanded. The facility produces Class A reclaimed water for groundwater recharge and reuse, primarily urban irrigation. LOTT's main facility, the Budd Inlet Treatment Plant, discharges to Puget Sound and has a stringent nitrogen limit of 3.0 mg/L for total inorganic nitrogen. The Martin Way satellite facility diverts a portion of the nitrogen loading from marine discharge.

The Martin Way Pump Station controls the relative division of flows. Incoming wastewater follows a typical diurnal variation. Flow to the satellite facility fluctuates diurnally and falls below the design capacity during the night and early morning. These fluctuations in flow can compromise biological process performance and result in increased effluent nitrate. When flow is low, flow to the Budd Inlet facility may cease, and the associated force main becomes stagnant.

The satellite facility includes a third aeration basin structure without installed equipment. An economic analysis was performed on alternatives to equalize influent flow to the satellite facility. Flow equalization was found to have the potential to stabilize the influent flow and increase the average reclaimed water production.

190,000-L (50,000-gal) peak flow equalization facility is located adjacent to the ski area and attenuates wastewater flowing to the MBR facility, allowing the MBR to operate effectively.

Case Study: Alderwood Water & Wastewater District, Picnic Point Wastewater Treatment Facility (Edmonds, Wash.)

The Picnic Point facility has a capacity of 15 ML/d (4.0 mgd) and uses flat-plate membranes. The facility began operation in 2011. In 2017, an assessment revealed that membrane permeability was declining gradually, as shown in Figure 2 (p. 38). In addition, an assessment of flow records indicated that peak flow events were increasing in number and magnitude. The district took two actions to manage declining membrane permeability and increasing peak flow.

The first step was to implement a fast-track project to not only replace the existing membrane cassettes in the four operating membrane tanks, but also to add membranes to two tanks constructed with the original facility, but for which membranes were not initially installed. Design and membrane procurement were performed in parallel. The two new sets of membranes and two replacement sets were installed in summer 2018, and the other two replacements will be completed in summer 2019.

The second step was to assess the feasibility of constructing a flow equalization facility. Hydraulic modeling indicated that a storage volume of 3.8 ML (1

Figure 4. Dispersed membrane foulant – before and after treatment with ferric chloride

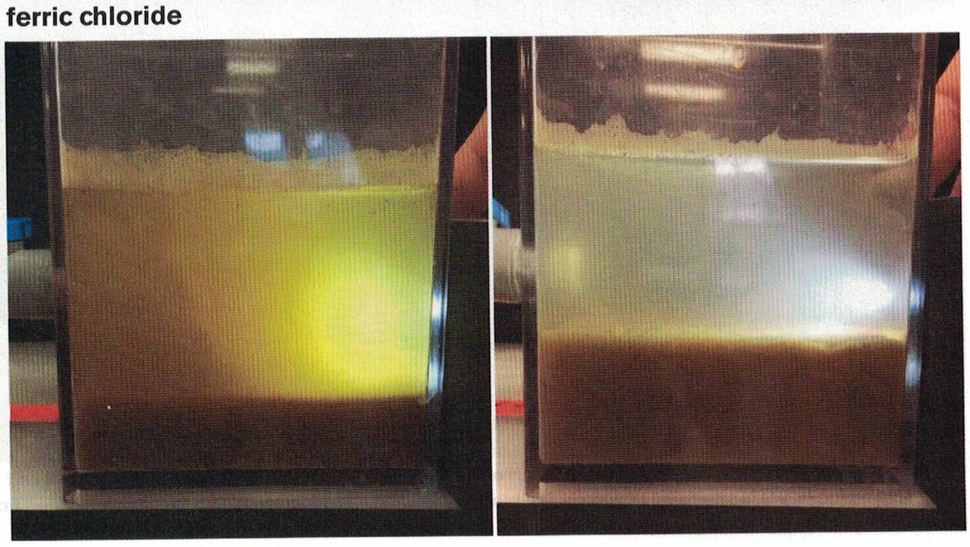


Figure 5. Debris fouling of tubular membranes

In addition, equalization would increase the diversion of nitrogen from marine discharge, an advantage particularly in the spring when high flow and cold wastewater temperatures impair nitrogen removal. Finally, equalization would sustain flow to the Budd Inlet Treatment Plant during the night, reducing the potential for force main corrosion. LOTT is using this information to explore the costs and benefits of combining equalization with other system improvements in the coming years.

Conclusion

Designers should plan for means to limit peak flow through membranes. Utilities that have implemented equalization have found it to be highly useful, and those that do not have equalization are considering it. Other wet weather flow management strategies may be feasible. A proposed MBR facility in Northern California incorporates a biological contact process for treating peak wet weather flow that exceeds membrane capacity.

No. 3: Cold water impacts

A crucial aspect is designing facilities to accommodate local conditions. Low temperatures affect both the physical permeability of the membranes and the treatment microbiology.

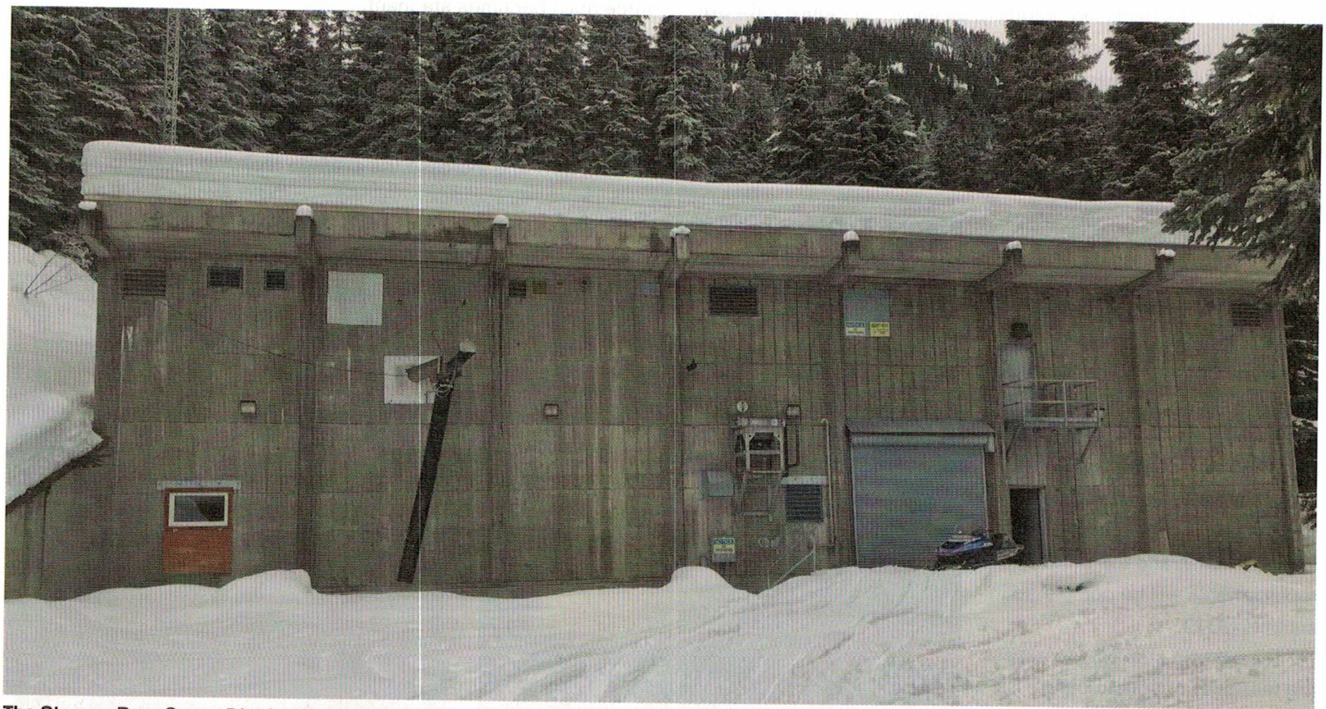
The first MBRs in the U.S. were constructed in the southeast, with warm wastewater temperatures. Therefore, new facilities were designed assuming high membrane flux rates (the ability to pass flow). However, cold wastewater temperatures experienced in the Pacific Northwest, typically when flow is highest due to wet weather, require specific design and operational approaches for reliable performance.

First, cold temperatures that impair membrane permeability and diminish flow need to be considered in selecting the design flux. Figure 3 (p. 39) shows the physical effect of temperature on membrane permeability. Due to water viscosity increase, a temperature decrease from 20°C to 12°C will decrease permeability by one-third.

Second, cold weather biological growth varies from warm water organisms and needs to be addressed in the process design. The growth of filamentous organisms is common in cold wastewater. Stressed organisms also may produce extracellular polymers that interfere with membrane filtration.

Case Study: Coeur d'Alene Wastewater Treatment Plant

The tertiary membrane demonstration facility provided an opportunity to assess the biological growth anticipated in the full-scale facility. During initial operation of the demonstration facility, membrane flux was found to be significantly less than anticipated. From microscopic examination of the organisms present in the



The Stevens Pass Sewer District Wastewater Treatment Plant in Leavenworth, Wash., serves a ski resort and a small residential area. The treatment facility is housed in a large building to protect the biology from the severe winters. This facility also added flow equalization to handle highly variable flows from the resort.

In the Pacific Northwest, 15 years of operational experience with membrane bioreactors has led to many lessons that can be applied to design and operation.

tertiary membrane filtration system, it was concluded that cold weather stress impaired performance of the treatment system. The biological process produced a fine foulant that decreased membrane permeability. Several options were tested at bench-scale to improve performance, including chemical addition and alternate membrane cleaning procedures. The addition of small amounts of ferric chloride (see Figure 4, p. 39) improved membrane permeability and restored hydraulic capacity.

Conclusion

During design, consider the effect of cold wastewater on membrane flux rates as well as the effect on the biological process.

No. 4: Wastewater contaminant control to protect membranes

Membranes must be protected from debris, grit, and other contaminants that physically or chemically interfere with membrane permeability. The presence of hydrocarbons in wastewater can impair membrane performance. Screens need to be compatible with the membrane type. Perforated screens provide better capture of debris than screens with slotted openings. For tubular membranes, 1- or 2-mm screen openings are required, but screen openings as large as 3 mm can work for flat plate membranes.

Case Study: LOTT Clean Water Alliance, Martin Way Reclaimed Water Plant

This facility uses tubular membranes and perforated plate screens with 3-mm openings to protect the membranes. Initial operation was plagued by low flux rate, with an excessive number of maintenance and chemical cleaning cycles.

The owner's staff inspected the membranes and found that excessive quantities of debris were accumulating within the membrane cassettes. (See Figure 5, p. 40.) Screen inspection and installation of temporary screening downstream found that significant debris quantities were escaping screening.

The solution was to install a secondary screen downstream of the initial screen. The new equipment included a drum screen with 2-mm openings, as a drum screen provides a tight seal between the screen and the channel, eliminating debris bypass. With installation of a secondary screen, membrane flux increased, maintenance and chemical cleaning decreased, and full facility capacity was restored. (For comparison, the previously mentioned Picnic Point Wastewater Treatment Facility uses 3-mm band screens before its flat-plate screens. The facility has not experienced issues with debris fouling the membranes.)

Case Study: Stevens Pass Sewer District Treatment Plant

In winter 2016, operators discovered hydrocarbon contamination in the influent entering the MBR facility. As hydrocarbons impair membranes, the manufacturer invalidated the warranty. The facility staff identified the suspected source of the contamination and implemented control methods. The owner replaced the membranes to sustain capacity.

Conclusions

Designers should consult with membrane manufacturers when selecting influent screens for untreated wastewater. Most membrane manufacturers recommend perforated screens, and not slotted units. Screen openings should generally be 2 to 3 mm for flat-plate membranes and 1 or 2 mm for tubular membranes. The use of two-stage screening is recommended for all but the smallest membrane bioreactor treatment facilities. Sources of unusual contaminants, particularly hydrocarbons and inorganic silt, should be controlled or eliminated.

No. 5: Membrane scouring air supply design

Membrane systems require a supply of scouring air to agitate the membrane cassette and prevent solids from accumulating on the surface. The air demand is variable, as the air supply needs to be high when permeate rates are high, and air supply curtailed when permeate is not flowing through the membrane.

In recent years, turbo blowers have become widely used in water reclamation facilities due to superior energy efficiency, low noise, and small footprint. However, these units operate at high speed and frequent stops and starts may cause excessive bearing wear and reduce equipment life.

Case Study: Picnic Point Wastewater Treatment Facility

The membrane scouring air supply system required additional capacity to accommodate an increase in installed membrane capacity from four to six tanks. With this modification, the owner also opted to assess and resolve issues with the existing scouring air system.

The original membrane scouring air system included five turbo blowers that discharged to a common air manifold. From the aeration manifold, a full-line size control valve adjusted flow discharging to a 150-mm (6-in.) diameter pipeline dedicated to each membrane tank. The membrane manufacturer's control panel dictated blower on–off, blower speed, and control valve modulation. The control system was designed to sustain the desired air flow to each membrane tank.

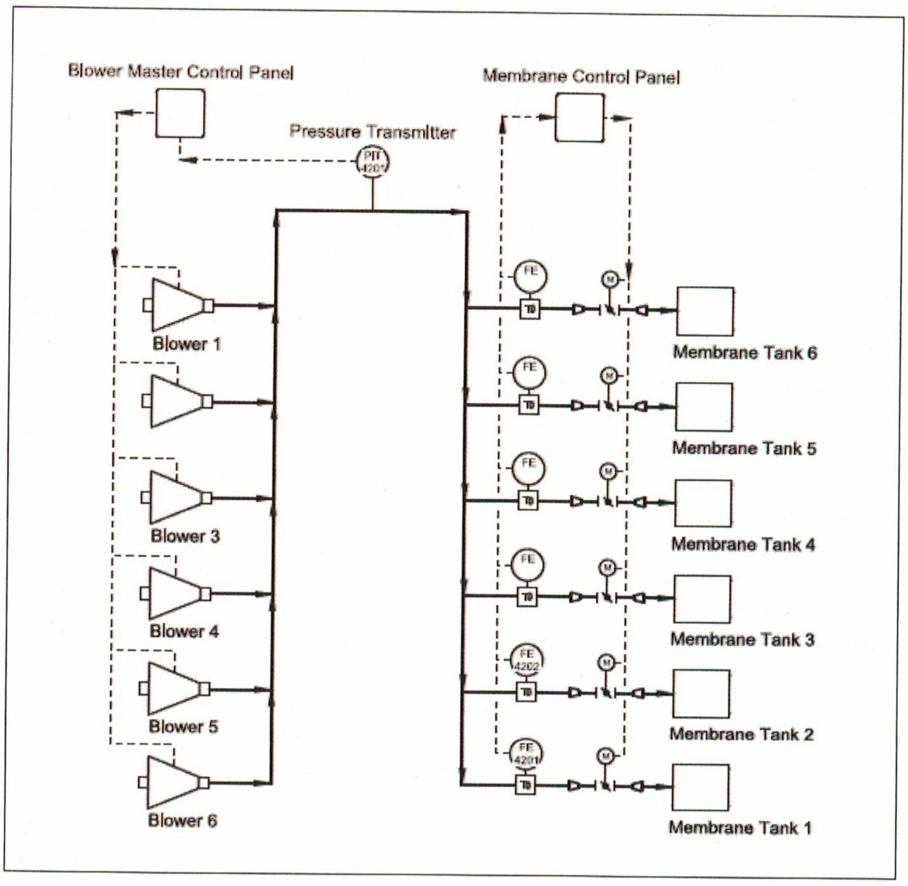
The engineering team found that the membrane scouring air supply system was ineffectively adjusting air supply to meet varying scour demands. Blowers appeared to be oversized, were operating in a start–stop mode, and experiencing wear from an excessive number of starts and stops. Control valves were operating at nearly a closed position and could not properly modulate air supply. The team identified interim operating adjustments to improve performance and permanent aeration upgrades to improve performance and decrease energy consumption.

The engineering team designed modifications to the membrane scouring air supply. Flexibility was included for operating in multiple controls modes, to be tested during commissioning. As shown in Figure 6 (below), the primary operating mode is for the blower manufacturer to control blower operation to sustain a pressure setpoint in the blower manifold, and for the membrane supplier to modulate only the control valves to achieve required air flow. When more air is required, the control valves open, causing pressure in the air manifold to decrease. The blower controls detect the reduced pressure and adjust blower operation and speed. When less scouring air is required, the opposite sequence occurs. This strategy places responsibility on the blower manufacturer to control operation to minimize equipment wear.

The improvements consisted of the following elements:

- Replace one turbo blower and add a sixth unit.
- Add a new master blower panel, using pressure setpoint control, to control the blowers. The blower manufacturer designed the control panel to limit blower starts and stops to prevent excessive wear.
- Replace existing air supply control valves with smaller-diameter units to improve supply control. By reducing the valve size, the valve will operate near the middle of the open/closed range with improved modulation of scouring air supply.
- Modify turbo blowers to add an idle mode, where the units will continue to operate when demand is low, but not discharge air.

Figure 6. Membrane scouring air supply schematic



This mode will avoid excessive starting and stopping and extend equipment life.

- Provide a new control panel that eliminates direct control of scouring blower operation. The new control panel uses only adjustment of the flow control valves.

The improvements were constructed during summer 2018. During commissioning, several blower operating modes were tested and elements of both pressure and flow control were retained by the owner. These findings support a design approach with multiple control modes to suit changing wastewater characteristics.

No. 6: Facility operation and maintenance planning

Membrane bioreactors are complex treatment systems with multiple mechanical, electrical, and instrumentation elements. Consideration for how the facility will be operated and maintained needs to start during planning and design.

Skilled operators are in demand and may be difficult to recruit. In some cases, private developers have conducted wide-ranging recruiting programs. Some agencies have elected to include operating services as a total package with facility design and construction.

Given the extensive number of moving parts, vendors typically prefer to incorporate Ethernet-based control systems with MBR packages to reduce the number of cables and connections.

Case Study: Alderwood Picnic Point Wastewater Treatment Facility

The Picnic Point MBR replaced outdated contact stabilization units located on a narrow site. The membrane tanks were constructed using common-wall construction, with limited clearance between the membrane cassettes and tank walls to minimize footprint.

Staff members have found that without primary sedimentation, silt accumulates within the membrane tanks and requires thorough annual cleaning. Typically, vactor trucks collect accumulated sediment, with operators monitoring this step. However, the tight spacing requires operators to enter the tank – a confined space – to support the cleaning process, but the constrained layout makes access challenging. (See Figure 7, below.)

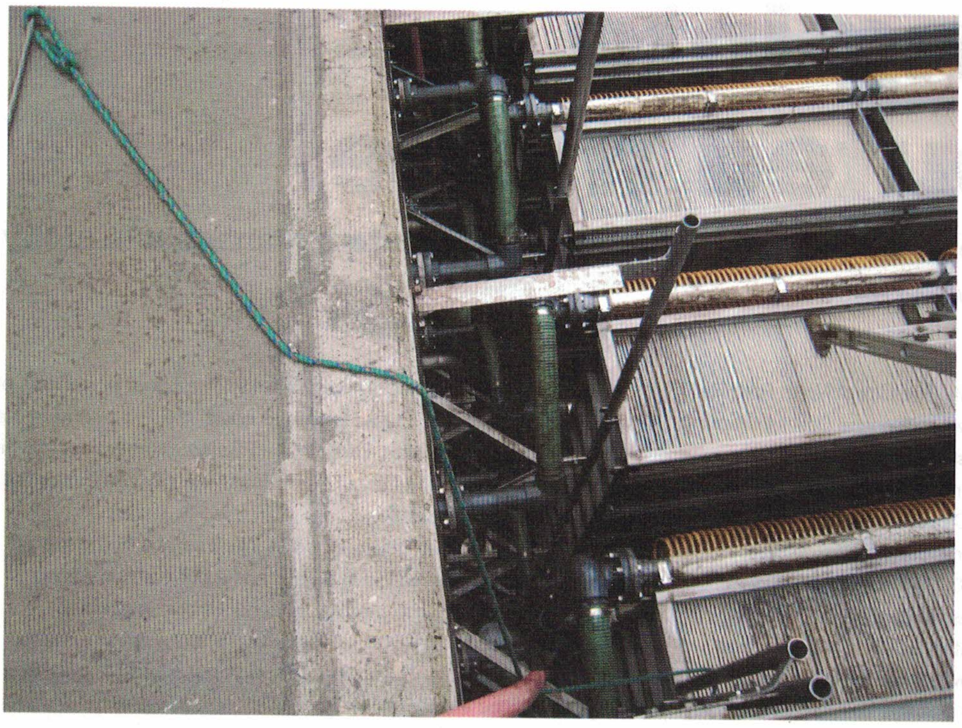
Membranes typically will need to be replaced every 10 years, but life can be less if exposed to unusual contaminants or operated at harsh conditions.

No. 7: Plan for future membrane replacement

Membranes typically will need to be replaced every 10 years, but life can be less if exposed to unusual contaminants or operated at harsh conditions. In 2003, when membrane bioreactors were first becoming widely used, only three manufacturers were producing commercially available products. Since then, original manufacturers have improved their products and more manufacturers have entered the market with innovative products.

Utilities should plan for future membrane replacement. In some cases, alterative membrane products can be retrofitted to facilities originally designed for a specific manufacturer's membranes. Likewise, membrane technologies are evolving rapidly, and it may be feasible to install an alternate membrane type in existing facilities.

Figure 7. Constrained access for maintenance, Picnic Point Wastewater Treatment Facility



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The author would like to thank the other team members from the LOTT Clean Water Alliance, Alderwood Water & Wastewater District, Stevens Pass Sewer District, the City of Coeur d'Alene, and the engineering group at HDR who participated in the projects discussed here.

Growing into a distributed model

Corralling 104 square miles and 85,000 individual lots into a manageable utility

Jennifer Desrosiers, Rick Newkirk, and Harold E. Schmidt Jr.

This is story about a community. The City of North Port, Fla., was born in the mid-1950s when General Development Corp. (GDC) took an interest in an area of land in southwestern Sarasota County known as the Charlotte Springs section of Port Charlotte. GDC platted, and subsequently sold individual lots – nearly 85,000 for residential development, which was later reduced to approximately 74,000 to incorporate larger tracts for residential and commercial land uses. To support their Florida developments with water and wastewater, GDC created General Development Utilities Inc. (GDU) as a wholly owned subsidiary of GDC. In 1992, the city the acquired the utility systems from GDC.

When the city was incorporated in 1959, it had a population of 23. After 20 years GDC had amassed nearly 44,515 hectares (ha) (110,000 ac) in Charlotte, DeSoto, and Sarasota counties, of which nearly half made up the City of North Port. The city has continued to grow in size and population.

North Port consistently has been ranked as one of the top 20 fastest-growing cities in the U.S. and has a current population of approximately 66,300 people. Its buildout population has been estimated at 268,000 people – that's more than four times the current population. Therefore, managing this utility's growth continues to be a daily challenge.