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American Membrane Technology Association

America's Authority in Membrane Treatment

Membrane Bio-Reactors (MBR)

The use of Membrane Bio-Reactors (MBRs) in municipal wastewater treatment has grown widely in the past decade. This trend is primarily due to more stringent effluent water quality requirements, decreasing system costs and improved energy efficiency. Moreover, in response to a changing economic climate, MBR is commonly viewed as an option for the retrofit, expansion and upgrade of aging infrastructure to meet new nutrient limits or increase plant capacity.

Wastewater treatment plants have historically required a significant amount of land to construct the necessary tanks and infrastructure for the required levels of treatment. MBR provides a cost effective viable alternative to conventional treatment within a considerably reduced footprint. Additionally, there is ever increasing regulation related to pathogens, viruses and other constituents of concern which are not typically reduced to desirable levels by conventional treatment processes.

New water is not easily created, but some communities are doing just that, by turning to more advanced processes, such as MBR systems, which make water recovery and reuse possible. MBR technology combines conventional activated sludge treatment with low-pressure membrane filtration, thus eliminating the need for a clarifier or polishing filter. The membrane separation process provides a physical barrier to contain microorganisms to assure consistent high quality reuse water. The ability to cost effectively treat raw sewage for reuse provides a new reliable, drought proof supply of water that can benefit communities by reducing reliance on over stressed existing supplies, increase availability of potable water and improve our environment by decreasing discharges of partially treated wastewater to oceans, lakes, rivers, streams and creeks.

MBR technology is also ideally suited for an array of municipal and industrial wastewater applications such as irrigation, aquifer replenishment, wetlands development, industrial process water, boilers and cooling systems. The scalability and portability of MBR technology has also created new opportunities for satellite and scalping treatment plants. Also referred to as point-of-use or decentralized plants, satellite facilities allow communities to remotely treat wastewater, thereby alleviating the need for expanding centralized sewage systems and long distance pipelines which can be disruptive and costly. In a related application, scalping plants treat raw sewage from existing regional sewer lines, producing recycled water for local use and before sending residuals back into the sewer system.

MBR systems offer a wide range of benefits, such as:

- MBR is capable of meeting the most stringent effluent water quality standards. More importantly, the effluent quality is highly consistent with the membrane barrier and a more stable biomass.
- Combining space efficient membrane systems and operation at increased mixed liquor concentrations (commonly 8,000 – 18,000 mg/l); MBR systems are highly space efficient. Commonly, MBR designs will require only 30 – 50% of the space required for conventional systems designed to meet the same treatment goals. This improved space efficiency benefits not only new facilities, but allows expansion and upgrade of existing facilities up to 3-5 times existing capacity without additional treatment volume or site footprint.
- MBR systems provide this high effluent quality in a greatly simplified process, requiring only headworks, biological process, membrane filtration, and disinfection to meet the most stringent water quality standards. In comparison, conventional process requires

additional primary treatment, secondary clarifiers, Enhanced Nutrient Removal and media filtration in order to obtain the same effluent characteristics.

- MBR systems are simpler with fewer process components and maintenance requirements. Common maintenance is still required on mechanical components, but operators can now avoid difficulties in operation tied to sludge settling and clarifier sludge blankets. MBR systems are also easily automated and instrumented to measure performance, allowing systems to be remotely operated and monitored, thus significantly reducing operator attendance.
- The modular nature of the membrane system allows more efficient phasing of facilities. Membrane modules can be delivered on a "just in time" basis, reducing the need for large and costly initial construction to meet long-term projections.
- The cumulative advantages of MBR are increasingly translating into lower total installed costs as compared to conventional activated sludge and SBR technologies. Cited cost savings often include reduced concrete, space and building sizes among other factors.
- The ability of MBR systems, Microfiltration or Ultrafiltration, to produce effluent with very low solids (SDI < 2) makes them well suited as RO pre-treatment.

MBR Wastewater Influent Limitation and Pretreatment

The membranes in a MBR system are made from polymeric organics (PVDF, PE or PES) and assembled into units (modules, cassettes, stacks) with high packing density. Raw wastewater pretreatment is important to sustain stable MBR performance and fine screening is an essential operation of any pretreatment system. MBRs have a limited tolerance for abrasive and stringy materials, such as grit, hair and fibrous material. This material, if accumulated in the mixed liquor to a sufficient extent, can cause membrane damage and accumulation of solids and sludge between membrane fibers and plates, or clog membrane tube openings. Depending on the type of membrane technology selected and specific project drivers, some combination of coarse screening, grinders, grit removal, primary clarification and fine screening is generally recommended as pre-treatment for MBRs. However, pre-treatment requirements can vary widely between technologies and treatment objectives. In fact, recent innovations in membrane equipment design are geared toward reducing pre-treatment requirements and equipment sensitivity to damaging debris.

MBR suppliers normally specify a fine screening requirement of <3 mm mesh or hole opening (with <2 mm preferred), while side stream MBRs will typically have a tighter requirement for fine screening. Fine screens are sized for peak flow with one screen out of service to prevent overflow or bypass of unscreened wastewater. Washing and compaction of screening solids are recommended where practical to reduce the water and organic content of the screenings. Fine screens in many different configurations are available, each uniquely fitting a particular need and application. Typical fine screen configurations include

rotating brush screens, internally-fed rotary drum screens, in-channel rotary drum screens and traveling band screens.

Oil and grease in the concentrations typically found in municipal sewage have little or no impact on the operation of an MBR, however free oil and grease must be removed as this can prematurely foul membranes.

Pretreatment of industrial wastewater varies from case to case because some industrial wastewater may have high COD (>10,000 mg/L), high temperature (> 40°C), high TDS (>20,000 mg/L) or high content of inorganic solids. Without proper pretreatment, these wastewaters may jeopardize MBR applicability or economic feasibility. Most industrial wastewaters do not require fine screening and some may need physical-chemical pretreatment, such as flocculation/ coagulation and/or dissolved air flotation (DAF).

MBR Effluent Water Quality Capability

One of the most important advantages of MBR over conventional biological technologies is the superior quality and consistency of the produced effluent. Historically, MBR operations have proven that the effluent quality can exceed the world's most stringent wastewater treatment standards, including: California's Title 22 reuse standards, European bathing water standards, US Coast Guard, United Nation's International convention for prevention of pollution from ships and Alaskan marine discharge standards.

Not only do MBRs ensure an effluent free of solids due to the positive barrier for suspended solids and colloidal materials, but also overcome the operational problems associated with poor sludge settling in conventional activated sludge processes while maintaining a considerably higher MLSS concentration and sludge retention time. Consequently, both soluble and particulate organics in waste streams are effectively oxidized, and nutrient removal can be readily accomplished through biological nitrification, denitrification and chemical or biological phosphorus removal.

MBRs have the capability to consistently achieve the following effluent quality:

BOD_5:	< 3	mg/L
TSS:	< 1	mg/L
NH_3-N:	< 0.5	mg/L
Total Nitrogen:	< 3	mg/L
Total Phosphorus:	< 0.05	mg/L
Turbidity:	< 0.2	NTU

The consistent high quality effluent produced by MBRs is suitable for a variety of municipal, industrial and commercial reuse purposes and can be applied in environmentally sensitive areas. MBR effluent is also an excellent water source for reverse osmosis applications to produce higher quality water for ground water recharge or industrial pure water reuse.

MBR Capital/O&M Ranges

As a result of widely varying conditions, costs for MBR systems can vary greatly. For both capital and operating costs, numerous factors will impact any particular project including:

- Membrane technology selected
- Local construction costs
- Redundancy requirements
- Hydraulic peaking factors
- Local power costs
- Project specific needs for the site, including plant buildings and enclosure
- Project size
- Materials of construction

However, to provide general guidelines we have made some general assumptions. For smaller facilities, not including package plants and less than 1 MGD, expected equipment costs should be $1.00 - $6.00 per gallon of plant capacity, with complete plant construction costs ranging between $5.00 and $22.00 per gallon of plant capacity (depending on design). Operating expenses for the combined biological and membrane systems, including power, chemicals, and membrane replacement should range from $350 - $550 per million gallons treated.

Facilities greater than 1 MGD typically see some efficiencies and economies of scale, with equipment costs of $0.75 - $1.50 per gallon of plant capacity and complete plant construction from $3.00 - $12.00 per gallon of plant capacity. Operational costs for these plants generally range from $300 - $500 per million gallons treated. Through improved products and more efficient design and construction, these costs continue to decline globally.

Other Considerations

For owners and utilities, there are a number of key factors to consider when contemplating selection of an MBR system. Capital costs for a typical MBR system have become more competitive and in many cases less than conventional tertiary or re- use, but still remain marginally more expensive depending on evaluation criteria and comparison methodology. However, MBR can compete economically with secondary treatment technology when nutrient limits are specified, space is limited, concrete is expensive or capacity is phased in over time. Regarding operating costs, although it is well documented that MBR systems are more energy intensive than their conventional treatment equivalents, significant gains in energy efficiency have been achieved in the last decade.

The hydraulic capacity of membranes in an MBR process is based on design flow rate criteria and temperature. Typically maximum day or peak hour flows at the expected coldest temperature will dictate the membrane surface area required for a treatment plant. The design flux (unit flow per membrane surface) is the single most important design parameter as it will dictate the surface area of membrane installed, impact membrane air scour requirements, chemical cleaning requirements, membrane replacement and warranty costs. Design flux is very site dependent and needless to say, requires careful consideration. In the past, MBR peak factors were limited to roughly twice the rated (nominal) capacity of the plant but suppliers are now employing novel approaches to storm flow management that can, in some cases, allow for much higher peaking factors.

A number of membrane configurations are commercially available and include hollow fiber (both reinforced and non-reinforced), flat plate or tubular. The differences between each of these types of membranes are significant and include materials of construction, chemical cleaning, pore size (ultrafilter vs. micofilter), air scour requirements, hydraulic configuration and membrane tank volume. Selecting the appropriate membrane configuration also requires careful consideration of robustness, operating flexibility, influent wastewater characteristics and operating costs for a given application.

Like all membrane facilities, periodic cleaning must be performed to remove biological and inorganic foulants. Initially, many MBR systems were submerged in the aeration basin requiring removal of the membrane elements or units for cleaning – this was very labor intensive, particularly as plant capacities expanded. The current trend is toward fully automated, in-situ cleanings and even chemical free technologies that minimize or eliminate the need for routine cleaning.

Membrane systems are highly automated processes and as such redundancy and reliability need to be evaluated through the design process. There are many approaches to build redundancy into an MBR process including specification of redundant trains, influent equalization (relevant for smaller facilities), stand-by power and, in some cases, hot back-up PLCs. The level of redundancy required is site specific and should properly account for available storage, overall number of process trains, reliability of power, and type of plant (end of pipe vs. water reuse facility) among other factors.

Years ago, when MBR was first introduced to the market, a perceived advantage was the decoupling of the biological process from solids removal. However, after more than two decades and based on nearly 6,000 installations worldwide, it is clear that mixed liquor characteristics can significantly impact membrane performance. Significant flexibility exists with the biological design associated with MBRs. Sound biological design such as maintaining adequate DO concentrations in aerobic reactors and proper selection of SRT is critical for overall good membrane performance. Biological process configurations options are extensive and systems can be designed for very low total nitrogen applications as well as biological phosphorus removal in addition to more conventional nitrification/denitrification systems.

Future of MBR

Market trends indicate MBR technologies will be increasingly utilized as part of wastewater treatment, water reuse programs to conserve our natural water resources and to provide new water sources. There are roughly 600 operating plants in the U.S. and 6,000 worldwide. From small, point-of-use plants to large 40 MGD municipal plants, MBR systems are now considered mainstream and widely accepted as best available treatment. Building on numerous system innovations, the technology is considered by many industry professionals to be “the treatment technology of choice” regardless of the size or application.

This type of support, coupled with industry improvements in the technology, will take MBR to the next level to become “not just an alternative” but “the treatment of choice” in the next few decades.

This material has been prepared as an educational tool by the American Membrane Technology Association (AMTA). It is designed for dissemination to the public to further the understanding of the contribution that membrane water treatment technologies can make toward improving the quality of water supplies in the US and throughout the world.

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