89 Membrane Bioreactor (MBR)

89.1 General

Membrane Bioreactors (MBR) combine conventional biological treatment processes with membrane filtration to provide an advanced level of organic and suspended solids removal, along with the capabilities of advanced level nutrient removal in wastewater. This process may be used to accomplish carbonaceous and/or nitrogenous oxygen demand reductions. The design should be based on experiences at other facilities and should meet the applicable requirements under Sections 40, 60, and 80.

This chapter contains criteria for low-pressure, vacuum, and gravity ultrafiltration or microfiltration membrane bioreactors. Typical membrane system configurations include hollow fiber, tubular, or flat plate. Any other membrane system configuration should be considered innovative treatment technology and conduct a pilot study.

89.2 Pretreatment

89.21 General

a. Pretreatment is critical in MBR plant design to ensure adequate protection of membranes from physical damage. All MBR systems require fine screening and grit removal to prevent membrane damage from abrasive particles common in influent sewage.

b. Removal of fibrous or stringy material is also important. This material can become entangled and wrap around the hollow fibers or stuck within the gaps between membrane flat plates. This can plug the membrane scour aeration systems leading to problems with operation of and potential damage to the system.

c. If the influent oil and grease concentration exceeds 100 mg/L, or if historic problems with fats, oils and grease (FOG) exist within the community, oil and grease removal may also be necessary to prevent membranes from being coated.

89.22 Bar Screens

A mechanically cleaned bar screen with a manually cleaned emergency bypass bar screen or self-cleaning screening device should be provided. Bar screens should meet provisions of Section 51.1.

89.23 Grit Removal

a. Permanent grit removal facilities meeting the requirements of Section 53 should be provided for combined sewer systems and sewer systems receiving substantial amount of grit.

b. If a plant serving a separate sewer system is designed without grit facilities, consideration shall be given to possible damaging effects on pump, comminutors, other preceding equipment, and the need for additional storage capacity in treatment units where grit is likely to accumulate.

89.24 Primary Clarification

Primary clarification must be considered for all plants. Proposals that do not include primary clarification should justify why primary clarifiers are not practical due to facility size constraints or limited benefit in comparison to the cost of handling primary solids.

89.25 Flow Equalization

Influent flow equalization shall be considered for all MBR systems. Flow equalization should meet requirements of Section 55.

89.26 Fine screens

a. Location

Fine screens should be located downstream of primary clarifiers.

b. Design

1. Coarse screens followed by fine screens may be used to minimize the complications of fine screening due to high flow restrictions and increased solid waste handling

2. Fine screens should be rotary drum or traveling band screen with either perforated plate or wire mesh

3. Fine screens should have an opening size between 0.25 mm – 2.0 mm for hollow-fiber and tubular membranes, or 2.0 – 3.0 mm screening for flat plate membranes.

c. Number of Units

1. A minimum of two fine screens should be provided, with each unit being capable of independent operation.

2. Capacity should be provided to treat peak design flows with one unit out of service.

d. Electrical Fixtures and Controls

Electrical fixtures and screening areas where hazardous gases may accumulate should meet the requirements of the National Electric Code for Class I, Division 1, Group D locations.

e. Servicing

1. Hosing equipment should be provided to facilitate cleaning.

2. Provisions should be made for isolating or removing units from location for servicing.

89.3 Tank (Reactor) Design

89.31 Capacities and Loadings

a. The design sludge retention time (SRT) should be at least 10 days but no more than 25 days. An SRT outside this range may be acceptable if supported by a pilot study.

b. The design hydraulic retention time (HRT) should be between 6 hours and 15 hours.

c. Organic loadings for reactors not required to provide biological nutrient removal should be in accordance with Section 82.31.

d. Organic loadings for reactors required to provide biological nutrient removal should be based on one of these models for nutrient removal:

- Modified Ludzak-Etinger (MLE);
- Bardenpho;
- Modified University of Cape Town (MUCT);or
- An alternative method approved by the Department

e. The food to microorganism (F/M) ratio for the reactors should not be greater than 0.1 for plants requiring nitrification and 0.3 for plants not requiring nitrification. Greater ratios may be accepted, if justified by a pilot study.

f. Bioreactor MLSS concentration should be in the range of 4,000 mg/L to 10,000 mg/L. Other values may be accepted, if justified to the Department.

g. Membrane tank MLSS concentration should be in the range of 4,000 mg/l to 15,000 mg/l. Other values may be accepted, if justified to the Department.

89.32 Arrangement of Tanks

89.321 General Tank Configuration

a. A system designed for enhanced nutrient removal (ENR) should include an isolated tank or baffled zone for anoxic treatment, anaerobic treatment, or both.

b. A facility designed for nitrogen or biological nutrient removal should contain a deoxygenation basin, a larger anoxic basin, or another method approved by the Department for decreasing dissolved oxygen concentration, if the recycled activated sludge is returned to an anoxic or anaerobic basin.

c. An advanced nutrient removal system should be designed with recycle rates sufficient to sustain the designed mixed liquor concentrations in both the aeration and anoxic basins; typically totaling 600% or more of the influent flow.

d. Facilities without advanced treatment should be designed with recycle rates sufficient to sustain the design mixed liquor concentrations; typically from 300% to 500% of the facility's influent flow.

e. A system with a peak flow rate that is greater than 2.5 times the average daily flow should use equalization storage, or reserve membrane capacity to accommodate the higher peak flow.

f. An inner-tank valve should be provided for refilling tanks when one is taken out of service. The valve should be placed near the inlet side of the tank(s) near floor level.

g. Each reactor should include a dewatering system and be provided with inter-reactor overflow to another aeration tank or a storage tank.

h. The hydraulic grade line calculations should consider, operating depth changes, operation during stream flooding elevations, future plant expansions, and potential for treatment units or pumps to be out of service.

i. Structures using a common wall should be designed to accommodate the stresses generated when one basin is full and an adjacent basin is empty. Every wall of the MBR should be water tight and resist buoyant uplift when empty.

89.322 Number of Units

a. Consideration should be given to dividing the required aeration tank volume into two or more trains at all plants.

b. For plants designed to receive maximum monthly average flow of 50,000 gpd or more, total aeration tank volume should be divided among two or more trains capable of independent operation.

c. A plant should be able to operate at normal operating parameters and conditions for maximum monthly average flow with one MBR unit or train out of service

89.323 Inlets and Outlets

a. Controls

1. Inlets and outlets for each aeration tank unit should be suitably equipped with valves, gates, stop plates, weirs, or other devices to permit controlling the flow to any unit and to maintain a reasonably constant liquid level.

2. The hydraulic properties of the system should permit the peak instantaneous flow, including the maximum sludge return flow, to be carried with any single aeration tank unit out of service.

b. Conduits

1. Channels and pipes carrying liquids with solids in suspension should be designed to maintain self-cleansing velocities or should be agitated to keep such solids in suspension at all rates of flow within the design limits.

2. Adequate provisions should be made to drain segments of channels which are not being used due to alternate flow patterns.

89.324 Freeboard

a. The tank should have a minimum freeboard of 18 inches at the maximum liquid level.

b. Where a mechanical surface aerator is used, the freeboard should be not less than three feet to protect against windblown spray freezing on walkways.

89.325 Froth Spray

a. Use of a froth spray system to cut down the foam in the aeration tank should be considered.

b. The froth spray pump(s) should preferably be located in the chlorine contact tank to prevent clogging of nozzles.

c. The froth spray lines in the aeration tank should point perpendicular to the flow.

89.33 Mixing and Aeration Equipment

89.331 General

a. Mechanical mixing independent of aeration should be provided for all plants designed to provide biological phosphorus removal or denitrification.

b. Provisions should be included to lift equipment for removal, installation, maintenance, and repair.

c. In the case where a crane may be needed to lift equipment, access for the crane shall be considered.

89.332 Mixing Systems

a. Mixing equipment should be of the number, size, and location to provide adequate mixing at the proposed length, width, and depth throughout the intended mixing phase. This determination should be based on manufacturer supplied test data on tanks of similar geometry.

b. The mixing equipment should be effective to provide a complete mix, with consistent dissolved oxygen throughout the basin.

c. The mixing system should be sized to thoroughly mix the entire basin from a settled condition within 5 minutes without aeration, regardless of tank geometry.

d. Specifications should require verification of the mixing effectiveness at system startup.

e. Mixing equipment should be provided in multiple units, so arranged and in such capacities as to meet the maximum mixing demand with the single largest unit out of service.

f. The mixing equipment should also provide for a mixing pattern that is unobstructed.

g. Floating mixers should be accessible, adequately moored to assure that they operate in the design location without interfering with, or stressing, any other tank or process function, and protected from excessive icing.

h. Unaerated (deoxygenation, pre/post anoxic, and anaerobic) zones should have submersible mixers or an alternative mixer approved by the Department.

89.333 Diffused Aeration Systems

Except as noted below, the diffused air system should meet requirements of Section 82.332.

1. The minimum oxygen requirement should be based on 1.5 lbs. of O_2 / lb. of influent BOD_5 to the reactor at design flow. Oxygen required for ammonia nitrogen removal should be based on 4.6 lbs. of O_2/lb. of influent NH_3-N to the reactor.

2. Due to higher MLSS interfering with oxygen transfer, a reduced transfer efficiency correction factor should be calculated in accordance with the following:
$$\alpha = e^{-0.082 \bullet MLSS}$$
Where MLSS is expressed in g/L, not mg/L

3. The design oxygen concentration ranges for aeration system sizing should be:

   i. no more than 0.5 mg/L O_2 in the anoxic zone,

   ii. between 1.5 mg/L – 3.0 mg/L O_2 in the aerobic zone, and

   iii. between 2.0 mg/L – 8.0 mg/L O_2 at the membranes.

4. Air operated pinch valves to control the flow in the reactors should be insulated to prevent freezing or located at places not affected by weather.

5. The blowers and piping required for aeration should be installed separately from the blowers and piping required for scouring of the membranes.

89.334 Mechanical Aeration Systems

The mechanical aeration system should meet requirements of Section 82.333.

89.4 Membrane Design

a. MBR processes should be based on maximum design flow rate criteria at the coldest expected wastewater temperature. Maximum day or peak hour flows at the expected coldest wastewater temperature will dictate the membrane surface area required.

b. Membranes need to be mechanically robust, chemically resistant to high chlorine concentrations used in cleaning, and non-bio-degradable.

c. Membranes should be made from the following materials

- Polyethersulfone (PES);
- Polyvinylidene fluoride (PVDF);
- Polypropylene (PP);
- Polyethylene (PE);
- Polyvinylpyrrolidone (PVP); or
- Chlorinated polyethylene (CPE).

d. The nominal pore size used in a MBR for microfiltration membranes should be at least 0.10 um but not more than 0.4 um.

e. The nominal pore size used in a MBR for ultrafiltration should be at least 0.02 um but not more than 0.10 um.

f. The MBRs should be designed for an average daily net flux rate of not more than 15 gallons per day per square foot of membrane area (gfd). A peak daily net flux rate equal to or less than 1.5 times the average daily net flux rate. An alternative flux rate may be approved by the Department.

g. Hollow fiber transmembrane pressure (TMP) should have an operational pressure range of at least 2.0 pounds per square inch (psi) but not more than 10.0 psi. The maximum pressure should not exceed 12.0 psi.

h. Flat plate TMP should have an operational pressure rate of at least 0.3 psi but not more than 3.0 psi. The maximum pressure should not exceed 4.5 psi.

i. Tubular, out of Basin TMP should have an operational pressure range of at least 0.5 psi but not more than 5.0 psi. The maximum pressure should not exceed 10.0 psi.

89.5 Membrane Operations and Cleaning

a. Membrane Operations

1. A facility should be able to operate at normal operating parameters and conditions for daily average flow with one MBR unit or train out of service.

2. Acceptable methods of providing redundancy are additional treatment trains, additional treatment units, or storage. Redundancy should be demonstrated to the Department in the Design Engineer's report and O & M Manual.

b. Membrane Maintenance

1. A means of completely emptying each reactor of all grit, debris, liquid, and sludge should be provided.

2. All equipment should be accessible for inspection, maintenance, and operation.

3. A sump should be provided in any basin with a flat bottom.

c. Membrane Cleaning

1. Air scouring of at least 0.01 standard cubic feet per minute of air per square foot of membrane area but not more than 0.04 standard cubic feet per minute of air per square foot of membrane area;

2. A mixture of air scouring with mixed liquor jet feed;

3. Back-flushing, as appropriate;

4. Relaxation, which is short periods of air scouring without filtration; or

5. Chemical cleaning:

i. The chemicals used in treatment and maintenance should not harm the MBR system or interfere with treatment.

ii. The chemicals, including concentrations and disposal methods, should be identified in the Operations & Maintenance (O & M) Manual.

89.6 Scum and Surface Solids Removal

a. Facilities or mechanism should be provided for scum and surface solids removal in each basin.

b. Scum and foam should not interfere with treatment or overflow a treatment unit.

c. Surface wasting of excess mixed liquor or skimmers may be used to control scum and foam.

d. Surface wasting may be performed in an aerated basin, a membrane basin, or both.

e. Entrainment by mixing should not be the sole means for the removal.

f. The design shall consider winter operation and address freezing concerns.

89.7 Controls and Operation

a. A minimum of two Programmable Logic Controllers (PLC) or microprocessors, programmed to meet the treatment requirements for the design loadings, should be provided.

b. The design and installation should consider all factors affecting the flow and organic loading for each cycle, such as diurnal, first flush, industrial, etc.

c. A means of reprogramming the process operations should be provided.

d. Both automatic and manual controls should be installed to allow independent operation of each tank.

e. An Uninterruptible Power Supply (UPS) or other similar equipment with electrical surge protection should be provided for each PLC or microprocessor to retain program memory (process control program, last known set points, and measured process/equipment status) through a power loss.

f. A means of recording and displaying all activities of the MBR process, including the sequence and set points, oxygen levels, turbidity and all alarms should be provided.

g. The continuous turbidity monitoring and time should also be recorded and displayed. This information should be available in a visual display as well as a historical record.

h. A scroll-through display that identifies each sequence and set point should be provided.

i. There should be an operator interface provided for operator adjustment of all sequences, set points, and other control logic.

j. All designs should include a "high flow" mode with a program that will recognize flow above the diurnal peak flow.

   1. All equipment and controls should be designed to accommodate this high flow mode and to optimize the treatment processes.

   2. A description of this control logic should be included in the Design Engineer's Report and O & M Manual.

k. All designs should include programming and operational capabilities for lower than average startup flows and loadings that may be realized during new system startup and/or other prolonged periods where the plant may experience flows and loadings less than the design criteria.

   1. The programming and controls should at least be able to provide for consistent, reliable treatment and operation at 25%, 50%, 75%, and 100% of the design flow and/or loading.

   2. A description of this control logic should be included in the Design Engineer's Report and O & M Manual.

l. Control panel switches should be installed for all of the following:

   1. Pumps: manual/off/auto
   2. Valves: open/close/auto
   3. Blowers and mixers: manual/off/auto
   4. Selector switch for tank(s) in operation/standby

m. Control panel visual displays should be installed for all of the following:

   1. Mimic diagram of the process that shows the status and position of any pumps, valves, blowers or aerators, mixers, and membranes;
   2. Process cycle and time remaining;
   3. Instantaneous and totalized flow to the facility and of the final discharge;
   4. Tank level gauges or levels;

5. Oxygen Monitoring; and
6. Airflow rate and totalizer.

n. Annunciator panel to indicate alarm conditions should include the following:

1. High and low water levels in each tank;
2. Failure of all automatically operated valves;
3. Membrane failure;
4. Blowers, if used – low pressure, high temperature, and failure;
5. Mechanical aerator, if used – high temperature and failure;
6. Pump – high pressure and failure; and
7. Mixers, if used – failure
8. Oxygen deprivation

o. A tank level system should include floats or pressure transducers.

1. A float system should be protected from prevailing winds and freezing.
2. A bubbler system in a tank level system is prohibited.

89.8 Disinfection

a. When chlorination is used for disinfection, the chlorine contact tank should be sized to assure a minimum contact period of 15 minutes at maximum flow rate unless flow equalization is provided. The dosage should confirm to Section 103.32.

b. All effluent sampling for compliance reporting should be conducted using an automatic sampler controlled by an effluent flow meter, and should include samples pre and post membrane filtration.

c. Log credit may be given for membrane filtration according to challenge testing that is verified through direct or indirect integrity testing to reduce the required chlorine concentration.

d. When other means of disinfection is used, the facilities should be designed to provide required disinfection at maximum flow rate unless a flow equalization tank is provided.

89.9 Monitoring

Monitoring can be done by indirect or direct methods. The following standards apply to monitoring equipment.

a. Indirect Integrity Method:

1. Sampling and flow measurement equipment should allow monitoring of the operation of each reactor separately.

2. All effluent sampling for compliance reporting should be conducted using an automatic sampler controlled by an effluent flow meter, and should include samples pre- and post-membrane filtration.

3. Continuous filtrate turbidity monitoring from each membrane train or cassette or an equivalent should be provided for operational control and indirect membrane integrity monitoring. The membrane unit effluent should be monitored independently for each membrane in operation. The continuous monitoring consists of tests being performed at least once every 15 minutes.

4. If turbidity is used for indirect integrity monitoring, the control limit should have a reading less than or equal to 0.5 nephelometric turbidity units. Two consecutive filtrate turbidity readings above 0.5 NTU on any membrane unit should trigger an alarm

5. The measurement of turbidity should meet USEPA approved analytical methods. These are as follows:

   - Hach FilterTrak Method 10133
   - Great Lakes Instrument Method 2 (GLI2)
   - Standard Method 2130B, Turbidity – Nephelometric Method
   - USEPA Method 180.1, Determination of Turbidity by Nephelometry.

b. Direct Integrity Method:

1. Direct integrity testing should be performed if credit towards chlorine disinfection is given. For pressure-based direct integrity testing, the procedure in the *Membrane Filtration Guidance Manual* (EPA 815-R-06-009) is applicable.

2. The direct integrity test should be responsive to an integrity breach on the order of 0.08 um or less. The resolution should be recalculated if the system backpressure is adjusted during direct integrity testing.

3. The direct integrity test should be able to verify a LRV equal to or greater than the removal credit awarded to the membrane filtration process. The maximum removal credit that a membrane can receive is the lowest of the LRV of the challenge test and the LRV of the direct integrity test.

4. A direct integrity test should be conducted on each membrane unit at a frequency of no less than once each day that the unit is in operation. This

testing should be conducted at the same time each day to maintain a consistent time interval between testing.