Technical Manual

MICRODYN-NADIR

MICRODYN BIO-CEL® MBR

Design Guidelines

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Table of Contents

Figure Index

Table Index

1 About this Document

This document describes the general idea of how to design a membrane bioreactor (MBR) plant with MICRODYN BIO-CEL® MBR membrane modules and is written for the designer. Please note that this document is primarily intended for municipal wastewater; designs for industrial wastewater may vary significantly.

Detailed plant specific data can be found in the Basic Design Sheet, which is provided by MICRODYN-NADIR for every quotation as a separate document.

1.1 Glossary

1.1.1 Membrane Separation Process

Average Annual Flow (AAF)

- Average daily flow rate that occurs over a 365-day period with the highest flow based on annual flow rate data.

Backwash

- Permeate flow from permeate to feed side (reversal of flow direction in contrast to filtration) for removal of cake layer built up on membranes.
- Also known as backflush or back pulsing.

Biofouling

- Layer of organic substances that forms on the membrane surface.

Cassette

- Stack of laminate membrane sheets inside the module housing.

Chemical Enhanced Backwash (CEB)

- A chemical cleaning solution that is added to backwash in defined periods.

Clean Water

- Water free of any particles and debris.
- TSS < 2mg/L, COD < 30mg/L

Concentrate

- Feed component which is retained by the membrane and accumulated in the process.
- Also known as retentate or reject.

Cross-Flow Aeration

- The constant turbulent flow along the membrane surface that prevents the accumulation of matter on the membrane surface.
- High velocity is generated transversely to the filtration area providing high shear forces.

Production Cycle

- Sequence of steps among filtration, relaxation and/or backwash.

Dead-End Filtration

- Filtration mode where the feed water is forced through the membrane surface via an applied pressure without any tangential cross-flow.
- Comparable to filtration through a coffee filter.

Feed

- Influent to membrane process.

Filtration Line

- Number of membrane modules that are connected to a shared periphery (permeate pump, aeration blower, etc.) and located inside the same filtration tank.

Filtration Tank

- Tank that contains only submerged membrane modules. A tank may contain more than one filtration line.

Flux

- Refers to the specific flow rate through the total active membrane area, usually in units of L/(m^2*h) [LMH] or gal/(ft^2*day) [GFD].

Fouling

- Membrane surface area is covered with organic and inorganic matter
- Typically results in a decline in membrane performance
- May be partly removed by chemical cleanings
- Distinction between inorganic (see Scaling) and organic fouling (see Biofouling)

Gross Flux (GF)

- Measured as the attainable flux during filtration phase.

Irreversible Fouling

- Foulants that cannot be removed by cleaning; membrane performance is compromised and may not be recoverable.

Laminate Sheet

- Two membrane layers glued from both sides onto a spacer used as a permeate drainage layer.
- Sheets are laminate cut to formats of different size.
- Able to be backwashed due to unique drainage layer.

Maintenance Cleaning

- Regular chemical cleaning for removal of fouling.
- Scaling removal by acidic solutions (e.g. citric acid).
- Biofouling removal by alkaline and oxidative solutions (e.g. sodium hypochlorite).

Maximum Day Flow (MDF)

- Average flow rate that occurs over a 24 hours period with the highest flow based on annual flow rate data.

Maximum Month Flow (MMF)

- Average daily flow rate that occurs over a 30-day period with the highest flow based on annual flow rate data.

Maximum Week Flow (MWF)

- Average daily flow rate that occurs over a 7-day period with the highest flow based on annual flow rate data.

Mechanical Cleaning Process (MCP)

- Mechanical Cleaning Process with granulate inside membrane bioreactor for better mechanical cleaning efficiency and reduction of chemical consumption.

Membrane

- Selective barrier which is responsible for retention of solids bigger than the pore size.

Membrane Surface Area

- Area available for filtration process.

Module

- Unit comprising membrane and housing as well as diffuser and base frame.
- One or more cassettes mounted to a module.

Net Flux (NF)

- Gross flux subtracted by regeneration modes relaxation and/or backwash.

Peak Hourly Flow (PHF)

- Maximum flow rate sustained over a one-hour period based on annual flow rate data.

Permeability

- Calculated as the flow through a specific surface divided by the applied pressure and required time, taken as flux divided by TMP and usually in units of LMH/bar or GFD/psi.
- Indicator of filtration performance and is used as the optimum monitoring parameter.

Permeate

- Water treated by membrane process; clean water.
- Also known as effluent or filtrate.

Recirculation

- Recycling of concentrate to the feed (e.g. filtration tank to aeration tank, aeration tank to anoxic tank for denitrification).

Recovery Cleaning

- Cleaning inside filtration tank or in an external tank.
- Chemical can be added by backwash or directly into the tank.
- Also known as intensive cleaning

Regeneration Mode

- Physical cleaning of membrane by backwash, relaxation, etc. to increase permeability again after filtration.
- Part of production cycle.

Reversible Fouling

- Fouling that is removable by regeneration modes.

Scaling

- Inorganic precipitants that accumulate on the membrane surface membrane
- Typically results in a decline in membrane performance
- May be removed by chemical cleanings

Soaking Time

- Period where the entire operation is stopped to allow chemical cleaning agents to diffuse into denser fouling layers to break it up.

Temperature Corrected Permeability

- Permeability considering the effect of temperature on viscosity.

TransMembrane Pressure (TMP)

- Pressure difference between the outside (feed/concentrate) and inside (permeate) of the membrane.

Turbidity

- Cloudiness of fluid that is used as a permeate quality indicator.

Venting

- Removal of air from the permeate line.

Yield

- Calculated based on gross and net flux and taking operational cycle into account.
- Also termed recovery.

1.1.2 Biology

Aerobic Zone

- A zone in the bioreactor that is characterized by high levels of dissolved oxygen.
- In this zone, the oxygen level is measured using DO meter and maintained at an optimal level by adding air.
- Zone where nitrification takes place.

Anoxic Zone

- A zone in the bioreactor that is characterized by low levels of dissolved oxygen.
- Zone where denitrification takes place.

Bioreactor System

- A system which supports a biologically active environment having both anoxic and aerobic zones used for treatment of wastewater.

Biochemical Oxygen Demand (BOD)

- Quantitative test measuring the amount of oxygen that is needed and consumed by the biology during digestion and is proportional to the number of organics in the wastewater sample.

Chemical Oxygen Demand (COD)

- Quantitative test measuring the oxygen equivalent to the organic material in the wastewater that can be oxidized chemically.

Food to Microorganism Ratio (F/M ratio)

- Parameter used for biological design showing the ratio of substrate present and available biomass and biological volume required for degradation of organic matter.
- Also termed organic loading rate.

Hydraulic Retention Time (HRT)

- Retention time of water (permeate) inside the system.

Membrane Bioreactor (MBR)

- Combination of membrane separation process and biological treatment.
- Decoupling of hydraulic retention time (HRT) and sludge retention time (SRT) due to membrane barrier.

Mixed Liquor Suspended Solids (MLSS)

- Weight of solids found in the sludge in biological and membrane tanks

Sludge

- The solids portion of the wastewater in biological and membrane tanks.
- Also termed mixed liquor.

Sludge Retention Time (SRT)

- Retention time of sludge inside the system.

2 Mechanical Pretreatment of Wastewater

The selection of appropriate pretreatment processes is essential for the efficient operation of the downstream processes in any wastewater treatment plant. In membrane bioreactors (MBRs), the pretreatment processes are especially important as certain materials may exacerbate the fouling processes or even cause immediate damage to the membrane.

Specific site parameters, such as size of plant, wastewater characteristics and variations in wastewater flow, determine the type and amount of pretreatment necessary for successful operation of the MBR. The complexity associated with additional pretreatment processes must be weighed against the advantages and possible disadvantages for the downstream processes, especially with respect to membrane fouling and membrane life.

Typical pretreatment processes include:

1. Coarse Screening
2. Grit Removal
3. Fat, Oil and Grease (FOG) Removal
4. Primary Clarification
5. Flow Equalisation
6. Fine Screening

Usually a combination of one or more pretreatment processes will be used depending on the size of the plant and the specific wastewater characteristics.
A proper pretreatment will ensure very low levels of trash and other harmful material in mixed liquor. The quantity of debris and trash in mixed liquor can be measured by an analytical method known as “Sieve Test”. Routine sieve tests of mixed liquor are used to assess the performance of pretreatment systems. The sieve test should be used initially to commission and test the sludge before exposing the membranes to mixed liquor. It should also be routinely used to monitor sludge.

The Sieve Test procedure is provided in Appendix: Sieve Test Procedures.

2.1 Coarse Screening

Coarse screening refers to screens of 6 mm or larger and are available in different types and configurations. Systems using MICRODYN BIO-CEL® MBR membrane modules don’t have specific requirements for coarse screening. However, the use of coarse screens upstream of the plant may be beneficial, for example:

1. Systems using BIO-CEL MBR modules require fine screening before membranes. Most fine screen suppliers require coarse screening ahead of their screen to minimize risk of frequent blinding of fine screens and overloading. This may also allow using smaller and less expensive fine screens.
2. When a primary clarification is used ahead of MBR systems, coarse screens are often recommended by engineers before clarification.

2.2 Grit Removal

Grit and sand are inert material and are removed using physical processes such as aerated grit chambers. The need for grit removal and its design is based on an assessment made by engineers for the entire wastewater treatment plant.

However, fine screen suppliers may require grit removal ahead of their fine screens to minimize wear and tear. This should be discussed with fine screen supplier. In some rare cases, wastewater may contain very abrasive and sharp-edged material that are often considered the same as grit and sand and are damaging to membranes. The method to characterize the abrasive nature of wastewater is called “Gold Number”.

The mixed liquor entering membrane filtration tank should have an acceptable “Gold Number”. The details are provided in Appendix: Abrasion Test and Limits for Use with Immersed Membranes. Again, this is not a common occurrence, but if wastewater is considered abrasive to membranes, then special attention should be given to grit removal to ensure these materials are removed as part of physical pretreatment.

2.3 Fat, Oil & Grease (FOG) Removal

Wastewater may contain a certain amount of FOG and most municipalities have discharge limits for FOG. Systems using MICRODYN BIO-CEL® MBR modules may handle the typical FOG content found in municipal wastewater. However, significantly higher amounts of free oil may be fouling to membranes and should be removed prior to membrane filtration stage.

FOG entering the MBR plant will normally form a scum layer in the biological tanks. This scum layer in biological tanks does not impact membrane performance. What is important is the leftover FOG and mostly free oil after the biological tanks entering the membrane filtration tank. It should be noted that FOG may also blind fine screens and the FOG content upstream of the plant is higher and the issue needs to be discussed with the fine screen supplier. The limits for FOG entering the MBR plant are listed below:

Table 1. FOG limits

FOG Limit	Recommended
FOG limit headwork	<150 mg/L
FOG limit filtration tank	<10 mg/L

2.4 Primary Clarification

Although a number of benefits are offered, primary clarification is usually only economical for larger applications. Implementation of primary clarification depends on the scope and specifications of a project.

2.5 Flow Equalization

Similar to conventional plants, flow equalization may be used in MBR plants to better respond to flow variations due to large short-term peak conditions. Flow equalization is suitable for large peak hourly to peak daily flow rates in small to medium size plants, but it is not practical for large plants (e.g. more than 50,000 m^3/d) or when handling peak flow conditions for more than a day.

In such cases, the alternative to equalization is to use additional membranes for peak events. This is a suitable option when there is not enough space for equalization tanks or when peak events are for longer periods such as seasonal peaks. The choice between flow equalization and extra membranes is an economical decision based on capital and operating costs based on engineering evaluation.

2.6 Fine Screening for MBR

The fine screening is the most critical component in the MBR pretreatment process. The fine screens must be selected, designed, installed, operated and maintained properly to ensure sufficient protection of membranes over the life of the membranes. It is important to test and verify the performance of the fine screening system for both hydraulic performance and removal efficiency to ensure they meet design specifications.

The fine screening requirements for systems using BIO-CEL MBR modules are as follows:

- Minimum: screens with ≤ 2 mm (0.08 inches) square shape mesh or round hole openings.
- Strongly preferred: screens with ≤ 1 mm (0.04 inches) square shape mesh or round hole openings.

- The screen design, installation and operation should not allow overflow or bypass of unscreened wastewater to the MBR system.
- Rotating brush screens are the preferred type of screens. In this design, the screen surface is attached to the screen frame and does not move. The wastewater passes through the holes of the screen and the rejected materials are removed from the screen surface using a set of rotating brushes. As the screen media does not move in this design, these types of screens do not have the problem that is often seen in regard to the failure of sealing of the gaps between moving parts. This is an important feature that prevents any bypass of unscreened wastewater through the moving parts of the screen.
- It is best to add a flanged overflow connection to an upstream pump station or off-line facility. This should not be connected to the MBR system. This is used to allow a controlled diversion of unscreened wastewater in case of a problem with the screen itself.
- It is recommended to install a sufficient number of screens where maximum wet weather influent wastewater flow can be treated with at least one screen out of service.

The screening requirements for industrial applications may be different from those for municipal applications depending on the nature of solids in wastewater and what needs to be removed prior to membranes.

The purpose of fine screening is to remove the trash and other material that may accumulate within the membranes and on membrane aeration system causing severe solid build up and potential damages. A proper pretreatment ensures longer membrane life and less need for membrane maintenance. The mixed liquor sieve test is an essential test to ensure the concentration of trash and other harmful material in mixed liquor is sufficiently low and acceptable for membrane filtration.

3 Basic Description of Biological Processes

3.1 Biological Processes in Waste Water Treatment

The main biological processes used in MBR systems are as follows:

Anoxic Zone: The primary function of the anoxic process is denitrification or nitrate reduction. In the absence of dissolved oxygen, the biomass oxidizes organics using available oxygen molecules from nitrate (NO_3^-). The reaction reduces nitrate to nitrogen gas which is stripped out in the subsequent aerobic processes under aeration.

Nitrate reduction (denitrification):

$$NO_3^- + \text{Organic Carbon (e.g., Sucrose)} \rightarrow N_2 + CO_2 + H_2O + OH^-$$

A mixer is installed in the anoxic tank to mix incoming screened wastewater with the mixed liquor returned from the aerobic tank at a predetermined recycle rate. This recycle rate is chosen to achieve an optimal bioreaction within the anoxic zone.

Aerobic Zone: After anoxic zone, the denitrified wastewater enters into the aerobic tank. Process air blowers feed fine bubble diffusers installed at the bottom of the aerobic tanks to provide oxygen for biomass in the aerobic zone. Air is dissolved and used by biomass under aerobic reactions. MICRODYN BIO-CEL® MBR modules should always filter mixed liquor from the aerobic zone.

A properly installed (as per manufacturer's specification) and functioning dissolved oxygen (DO) sensor must be used to ensure the required level of oxygen in the aerobic tanks is present for the aerobic digestion. In this oxygen-rich environment, organic materials (as measured by BOD testing) and ammonia are biologically oxidized to carbon dioxide, nitrate and water.

BOD reduction:

$$\text{Organics} + O_2 \rightarrow CO_2 + H_2O + \text{New Cells} + \text{Energy}$$

Ammonia reduction (nitrification):

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + \text{Loss of Alkalinity}$$

From the aerobic tank, wastewater is pumped or fed under gravity to the membrane filtration tanks to separate water from biomass. Return activated sludge (RAS) overflows or is pumped from the membrane tanks into the anoxic zone (when applicable). This circulation flow is used to maintain a moderate level of mixed liquor suspended solid (MLSS) concentration in the membrane tanks. In some cases, membranes are installed in the same aerobic zone and mixed liquor is circulated from aerobic tank back to anoxic zone (when applicable).

Anaerobic Zone: In some applications, anaerobic reactors (no oxygen) are used to digest very high organic loading wastewater and reduce it to levels that can be further treated in aerobic bioreactors before being filtered by membranes. Anaerobic processes might also be used ahead of aerobic bioreactors with proper recirculation to remove phosphorous in a biological process.

Phosphorous Removal: Phosphorous removal can be achieved either biologically or by adding coagulants. The biological processes involve anaerobic bioreactors. The coagulant use is the most common method for phosphorous removal. There are different coagulants and they are dosed based on phosphorous content and desired removal rate. The coagulant and adsorbed phosphorous result in higher MLSS values, but act as inert in overall biological reactions. While their contribution to MLSS should be considered for solid mass flux (SMF) calculation, aeration and cleaning requirements, they should be excluded from total MLSS for biological activities of the mixed liquor.
The most common biological configurations before membrane filtration step are as follows:

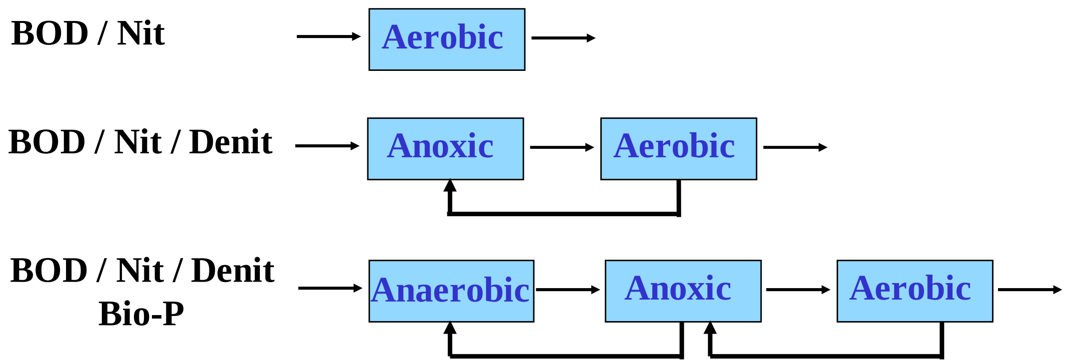

Figure 1. Overview biological configurations

In any biological configuration, the membranes should always filter mixed liquor from aerobic bioreactor. The mixed liquor is then recirculated and returned from membrane tank (in external configuration) or from aerobic tank back to the other zones depending on overall process configurations. However, from the membrane point of view, the design considerations are always related to aerobic bioreactors.

3.2 Municipal versus Industrial MBR Applications

For municipal applications, pertinent national standards must be considered (e.g. the German Standard ATV-DVWK A131 or the EPA 625/4-73-003a standard). A typical municipal MBR is a wastewater that has less than 20% industrial effluent and the rest is common municipal effluent. The biological design basis and considerations are similar for different municipal MBR with some variations mostly related to factors such local climates, desired MLSS content, nutrient removal and discharge requirements.

On the other hand, industrial wastewater can vary greatly from application to application. The design basis and considerations vary greatly between them. The presence of solvents, high levels of inorganic, highly loaded wastewater and specific chemicals alter the biology and its design basis. Therefore, piloting is recommended to ensure proper degradation of contaminants and chemicals that are degrading to membranes and to confirm flux rates and cleaning requirements. MICRODYN-NADIR has extensive experience for a wide range of industrial applications and should be contacted to provide support for biological designs, membrane operational conditions and pilot testing.

3.2.1 Textile

Waste water from textile industry is typically characterized by high temperatures (30-40°C [86-104°F]), medium to high organic pollution (~4000mg/L COD) and often dissolved dye. Depending on the process, the water may also contain TN in concentrations >10% of COD. The pH is usually high and needs to be neutralized.

Pretreatment is a must, minimum is a flotation to reduce the SS and COD, better is a flotation with coagulation and flocculation.

Recommended Flux despite the high temperatures is around 15LMH (8.82 GFD).

Reuse may be challenging, as the dye is not removed by the MBR treatment and will lead to a colored permeate.

3.2.2 Food and Beverage

Food and Beverage waste water is divers, it can come from many different sources like dairy, breweries, meat processing, fruit processing and potato chips manufacturing to give some examples.

The waste water typically has a very high BOD and COD concentration, ammonia and phosphorus can be high as well and TSS and FOG are often present in large quantities. The BOD/COD is generally readily biodegradable. Pretreatment should be able to reduce the BOD/COD, TSS and FOG to acceptable levels for the MBR process.

The main motivation to use MBR technology in F&B plants is water recovery and reuse.

Flux rates applied in F&B application can vary but are in general on the lower end of the scale, typically around 10-15LMH (5.88 – 8.82 GFD).

3.3 Basic Biological Design Requirements

While there are several different biological processes and system configurations, one thing remains constant – the sludge must be separated from the liquid phase. The MICRODYN BIO-CEL® MBR membrane modules can work with a variety of MBR systems provided they result in a biology that is working properly.

The performance of systems using BIO-CEL MBR modules depends on the whole process including biological treatment process and mixed liquor quality. The mixed liquor filtered by the systems using BIO-CEL MBR modules must meet the quality requirements listed in **Table 2**. This list is intended for municipal wastewater treatment and additional criteria may be required for other applications. The specific effluent quality requirements may also require additional mixed liquor qualites that are not listed here. MICRODYN-NADIR should be consulted for specific cases.

Table 2. Sludge characteristics of a well working biology

Parameter	Required	Recommended	Comments
MLSS Biology	<12 g/l	6-10 g/l	
MLSS Filtration Tank	<15 g/l	8-12 g/l	Consider the SMF limitations (see 4.4.1)
Sludge Loading Rate (F/M Ratio)	0.1-0.22 kgCOD/(kgMLSS·d)	0.10 to 0.16 kgCOD/(kgMLSS·d)	This assumes the sludge has a typical MLVSS/MLSS ratio of 0.75-0.8. In case of high inert content, the lower F/M-ratio should be used. Alternatively, the F/M-ratio can be expressed as recommended range of 0.13-0.19 kg COD/(kgMLVSS·d).
Dissolved Oxygen (DO)	>0.5 mg/L	≥1.0 mg/L	
Redox Potential	>-50mV	>0mV	
Sludge Time to Filter (TTF)	< 200 s	<100 s	
The Sludge Colloidal TOC	< 20 mg/L	<10 mg/L	
Sludge Volume Index (SVI)	< 200 ml/g	< 150 ml/g	Values higher than 200 ml/g will require biological optimization.

Table 2. Sludge characteristics of a well working biology

Parameter	Required	Recommended	Comments
Sludge Retention Time (SRT)	> 15 d	16-22 d	A sludge age of 10 days is acceptable for tropical systems with complete nitrification and denitrification.
Hydraulic Retention Time (HRT)		> 6 h	

Notes:

1. The sludge must be aerobically biodegraded until all residual BOD is removed and only a residual COD is present as hard COD (non-biodegradable).
2. While complete nitrification and denitrification processes are not required for membrane operation, better membrane performance is seen in systems with complete nitrification and denitrification.
3. Diluted sludge volume index (DSVI) values must be achieved without addition of special polymers. These polymers should only be used if the biological process is deteriorating.

In order to maintain good operating conditions for the membranes, the effluent of the biological treatment should fulfill the following requirements:

Table 3. Effluent characteristics of a good working biology

Parameter	Required	Recommended	Comments
Temperature	5 - 40ºC (41-104°F)		Lower temperatures will inhibit the bacteria and cause insufficient BOD/COD removal
pH	6 - 8	7	
Soluble BOD_5	< 5 mg/L	< 1 mg/l	
Soluble COD	< 50 mg/L	10-30 mg/L	
Soluble ammonia	< 2 mg/L	< 1 mg/L	Must be < 2mg/L 100% of the time
Total hardness (as $CaCO_3$)	-	-	Should not scale, influences cleaning procedure
Trash content	< 1 mg/L of material greater than 2 mm < 10 mg/L of material greater than 1 mm		Tested monthly as per Sieve test instructions

Notes:

1. Soluble COD for industrial applications may be higher. These limits are for municipal wastewater treatment and required permeate quality.
2. Trash content measurement is discussed in the pretreatment requirement chapter 2.6 and details are provided in Appendix: Mixed Liquor Sieve Test.

3. Scaling due to hardness is a function of water chemistry, temperature and pressure. More details and guidelines are provided under chapter 4.3.
4. For optimal membrane performance, shorter filter time is desired. Other sludge characteristics such as colloidal TOC may also be measured and monitored as part of mixed liquor management and achieving best membrane performance. Details on mixed liquor quality management is provided in Appendix: Mixed Liquor Sieve Test along with test methods.
5. Allowable FOG values are listed in chapter 2.3.

The MBR system should have proper pretreatment, as discussed in the pretreatment chapter (chapter 2), to remove sufficient amounts of FOG, sand and coarse materials, and trash using fine screening. These are not part of the biological design but will impact the overall sludge quality and membrane performance.

3.4 Oxygen Transfer

The alpha factor (defining the oxygen transfer in activated sludge compared to the clean water transfer) decreases with increasing MLSS concentrations. In standard MBR systems (municipal wastewater), operated with MLSS concentrations between 8,000 and 12,000 mg/L, an alpha factor of 0.5 for fine bubble diffuser systems may be used to calculate the effective oxygen transfer. The alpha factor may be increased if the MBR is operated with lower MLSS concentrations. Industrial applications with a high salinity may show lower alpha factors, even lower than 0.5.

The MICRODYN BIO-CEL cross-flow diffuser system can extensively contribute to the oxygen supply of the biology. A specific standard oxygen transfer rate (SSOTR) of about 12 $g_{oxygen}/(m^3 air \cdot m_{diffuser\ depth})$ has been proven under standard conditions. The SSOTR is increased if the air supply is being reduced. This is always contingent on the application. Please get in touch with your MICRODYN-NADIR representative for further information.

The maximum oxygen transfer strongly depends on the specific installation conditions. The lowest oxygen transfer may be achieved if the modules are installed in separate filtration tanks. The maximum transfer may be achieved if the modules are installed in larger tanks where the introduced DO can be easily consumed by the biomass.

The DO in the filtration tank is typically higher than the DO in the aeration tank, allowing the usage of the filtration tank as additional biological treatment. Designs made for plants located in Germany will not include the volume of the filtration tank to the total aeration volume. The German design rules (DWA-M 227) do not allow this. For plants outside Germany, the volume of the filtration tank is factored in to the total aeration volume.

4 Process Design for MICRODYN BIO-CEL® MBR Modules

4.1 Design Flux Rates & Calculation of Required Membrane Surface

There are two critical parameters to consider when calculating the required membrane surface area:

- Net flux rate
- Solid mass flux (SMF)

The net flux rate is the net amount of permeate produced over a period of time divided by membrane surface area. Solid mass flux represents the amount of solids that are being filtered by membrane over time. SMF is the product of net flux (l/m²h) and the MLSS in the membrane tank (g/L) and is expressed in g/m2/h.

The required membrane surface area is calculated based on different net design fluxes (e.g. annual average, max month, max week, etc). The calculated required membrane surface area may be different, but the highest amount is chosen to ensure the plant can meet all different operational conditions.

The design flux is affected by the following factors:

- Type of wastewater such as municipal, industrial, etc.
- MLSS concentration in the membrane tank
- Mixed liquor temperature; minimum temperatures are more critical
- Peak flow rates (e.g. peak hour, maximum day, maximum week, maximum month); definitions of these peak flow rates are provided in the Glossary, chapter 1.1.
- Duration of peaking conditions
- Number of trains or modules going offline during cleaning or maintenance, duration and frequency of such events and required flow rates when trains or modules are offline

The minimum temperatures are the most critical as fluxes are lower and the required membrane area should be checked for lowest temperatures as well. A more accurate flux design is possible if a yearly temperature and flow profile is available. The typical requirement for cleaning and maintenance is to ensure plant capacity is met while one train is offline (e.g. n-1). This means the remaining membranes should have net fluxes that are still acceptable as per this design guidelines or more membranes might be required to meet the net design fluxes.

Additionally, if the wastewater flow varies greatly, a buffer tank should be considered in order to reduce the required membrane area. A buffer tank might be a more economical option than adding more membranes. Selecting the design flux requires experience and detailed project information. As such, flux selection might be a balance between capital and operating costs and risks.

Low water temperature consideration: low mixed liquor temperatures impact the biological efficiency and water viscosity in a negative way. As such, it is important to ensure sufficient membranes are installed to meet plant capacity during low temperatures.

High salt concentrations (salinity): high salinity in mixed liquor can negatively affect the system since the biological community might be different. Landfill leachate can show a conductivity up to 50,000 µS/cm corresponding to a TDS of 25,000 ppm (depending on the wastewater composition).

When designing a system using MICRODYN BIO-CEL® MBR membrane modules, there are two flux values which must be considered: Gross Flux and Net Flux. Gross flux is the instantaneous, "real" flux through the membranes, and the net flux is the average flux with consideration of relaxation and backwash. The higher gross flux must be considered when sizing the permeate pump and the net flux is the determining factor when dimensioning the membrane surface area. The gross flux is dependent on the net flux (NF), filtration time (FT), relaxation time (RT), backwash time (BT), and backwash flux (BF). The formula below can be used to calculate the gross flux:

$$GF = \frac{(FT + RT + BT) \times NF + BF \times BT}{FT}\ [LMH]$$

4.1.1 Design Net Flux (Municipal)

MICRODYN-NADIR is using net flux tables to determine the plant size. Each table contains net fluxes for different temperatures.

Please note that the maximum design fluxes do not apply to the following cases:

- Industrial wastewater application
- Municipal applications where industrial wastewater contribution exceeds 25% of the mass load of COD

There are three different flux tables for different operation conditions:

1. BASIC:
   a. Small plants with minimal automation
   b. Customer focus on minimizing chemical cleanings
   c. Energy demand not an issue

2. AVERAGE:
   a. Standard design flux for most plants
   b. Max flux level for BIO-CEL 104, BIO-CEL 52 and BIO-CEL XS

3. ADVANCED
   a. Larger plants with full automation
   b. Customer focus on low energy demand
   c. Customer focus on minimizing membrane surface
   d. Fully automated chemical maintenance cleaning
   e. Only applicable for BIO-CEL L-2 and BIO-CEL XL-2

Separate flux tables are provided for industrial wastewater treatment.

The flux can be increased under certain environmental and operational conditions. But any design using higher numbers than stated above requires the approval of the Global Technical Service Manager.

4.1.2 Design Net Flux (Industrial)

The design flux for industrial applications is much more difficult to determine, due to the vastly different sources and compositions of the wastewater. One of the most important factors is the biodegradability of the wastewater. Accurate flux rates may have to be determined by piloting.

4.2 Filtration-Backwash-Relaxation Cycles

The main operation of MICRODYN BIO-CEL® MBR membranes involve repeated cycles of filtration followed by a short interval of mechanical cleaning that may consist only of backwash, relaxation or a combination of the two.

Filtration refers to the pulling of feed water through the membrane (from the outside of the membrane to the inside) to produce permeate. During filtration, there is a net flow of mixed liquor or feed water solids towards the membrane surface. Some of this solid accumulation at membrane surface is reduced by utilizing membrane aeration.

Relaxation refers to a short period when filtration is stopped (by stopping the permeate pump or closing the permeate valve), but membrane aeration is continued. During relaxation, there is a net flow of mixed liquor or feed water solids away from membrane surface due to the effects of membrane aeration and lack of filtration.

Backwash refers to a short period when permeate flow is reversed through the membrane so that permeate flows from inside of the membranes to the outside. During backwash, there is a net flow of mixed liquor or feed water solids away from membrane surface due to the combined effects of the membrane aeration and the backwash of permeate.

The backwash cleaning uses permeate produced during the production mode and is returned either from a permeate collection manifold or directly from a CIP/backwash reservoir. Permeate is pumped back through the membranes at low pressure and high flow rates. The duration of the filtration cycle is the sum of the filtration duration plus the relaxation/ backwash duration and the time required for valve switch-over.

Backwash or relaxation (depending on operation type) occurs automatically during a normal production cycle. The duration and frequency is an input depending on types of operation. The duration can be fine-tuned by the operator to address varying operational conditions.

The following table shows the range of acceptable durations for filtration, relaxation and backwash as well as recommended durations.

Table 4. Standard Operation Cycle

Standard Operational Cycle	Standard Range	Standard Range: Backwash Only	Standard Range: Relaxation Only
Filtration	510 s	570 s (480 to 720 s)	540 s (480 to 720 s)
Relaxation	30 s	-	60 s (30 to 120 s)
Backwash	30 s	30 s (15 to 60 s)	-
Relaxation	30 s	-	-

Notes:

- The values in the table above are standard values to start with. If the performance is not within acceptable ranges, the filtration, relaxation and/or backwash cycle time may be increased/ decreased accordingly. Be sure to consider that the net flux will increase if filtration time is increased.
- A too short backwash and/or relaxation time may reduce physical cleaning efficiency and may cause excessive or irreversible fouling. The chemical cleaning frequency may also increase.
- Backwash affects the system's efficiency since produced permeate is returned into the process fluid and must be re-extracted.
- It is important to allow enough time for the pump to ramp up and ramp down during backwash only cycles. This will prevent the membranes from experiencing sudden pressure shocks. More details may be found in the PLC description in chapter 7.

Use of Relaxation Alone

The use of filtration/relaxation allows for similar performance as the use of filtration/backwash for most MBR applications under normal operating conditions. The benefits of relaxation include a reduction in the amount of permeate used for membrane maintenance, an increase in system recovery and a reduction in the capital costs associated with backwash. Because of this, the default design for systems using MICRODYN BIO-CEL® MBR modules will only have the option for filtration/relaxation cycles.

BIO-CEL MBR membranes are designed to have the ability to be backwashed, providing additional capability to ensure stable operation. The following situations are examples where backwash may provide more process stability:

- During plant seeding and start-up
- During plant upset conditions
- MBRs treating difficult industrial wastewaters

Adding backwash may be decided upon cost and risk analysis and depends on the specific application. In the case that the designer decides to include backwash, the following guidelines are recommended.

Backwash Guidelines

The backwash system is designed to be able to deliver a backwash flux of 10 lmh (5.88 gfd) for all types of wastewaters. The maximum TMP during backwash should not exeed 150 mbar (2.2 psi).

If the backwash system is also used for membrane chemical cleaning purposes, the backwash system may have to fulfil higher material standards than if used for water alone.

The backwash system, like other parts, should be designed considering the future plant's needs such as expansion and potentially higher flow rates. For example, the tank may be sized for additional modules for future expansion. This needs to be taken into account when sizing system components.

Operational Considerations

In actual operation, the operator has the ability to adjust most parameters in the PLC. Operational sequences and plant specific water levels will be set during the commissioning. For more detailed information about this, please refer to chapter 7.

4.3 Membrane Cleaning

Depending on the type of fouling and required cleaning, a sodium hypochlorite solution, citric acid solution or combinations of the two may be required. Sodium hypochlorite is used to remove organic and biological fouling from the membrane while citric acid is used to remove mineral scaling such as iron, metal salts or calcium salt and other scaling compounds.

For more severe fouling, MICRODYN-NADIR may be contacted for alternative chemical cleaning solutions and procedures. These approved cleaning chemicals and procedures should be used in accordance with the procedures provided by MICRODYN-NADIR.

During normal operation, membrane surfaces may be fouled with particulate material including biomass, salt precipitates and insoluble organics (such as oil). These deposits may build up if not adequately controlled through use of mechanical cleaning procedures (e.g. relaxation, backwash and aeration). The continued growth of such deposits may eventually result in a decline in membrane performance (e.g. loss of membrane permeability). Please note that permeability may also drop if the process temperature drops; this decrease does not necessarily indicate membrane fouling.

Chemical Cleaning Procedure

MICRODYN-NADIR recommends two types of chemical cleaning procedures. General guidelines for membrane cleaning is summarized in **Table 5**.

- **Maintenance Cleaning:** performed once or several times a week using lower concentrations of chemicals for short periods of time (e.g. an hour). This cleaning is intended to maintain a sanitized system and to prevent significant growth of fouling deposits on membrane surfaces. It is recommended to set up the systems to perform maintenance cleaning automatically.
- **Recovery Cleaning:** performed once or few times a year using higher concentrations of chemicals for several hours. This cleaning is intended to remove all fouling residuals from membrane surfaces and "recover" membrane permeability

close to its initial or acceptable value. Such cleaning is recommended at least on an annual basis to ensure membranes are not irreversibly fouled or damaged and should be done even if membranes are performing adequately. It is recommended to use warm water for a higher efficiency of the cleaning.

-

Table 5. General Guidelines for Membrane Chemical Cleaning

Chemical	Target Species	Concentration	Backwash Flux	Cleaning Time
Standard Maintenance Cleaning in-situ (with mixed liquor in tank)				
Sodium Hypochlorite (e.g. 12%)	Organic & Biofouling	200 mg/L	10 L/m²/h (5.88 gfd)	60 minutes, 1-2 times per week
Citric Acid	Inorganic Scaling	2000 mg/L	10 L/m²/h (5.88 gfd)	60 minutes, 0-1 time per week
Standard Recovery Cleaning (in chemical solution)				
Sodium Hypochlorite (e.g. 12%)	Organic & Biofouling	2000 mg/L 30°C < T < 40°C (86°F < T < 104°F)	n/a	12-16 hours
Citric Acid	Inorganic Scaling	5000 mg/L 30°C < T < 40°C (86°F < T < 104°F)	n/a	12-16 hours

The frequency of cleaning depends on several factors such as:

- Type of wastewater
- Chemistry of feed water
- Scaling potential
- Operating temperature
- Pretreatment efficiency
- Completeness of biological degradation
- Permeate flux rates
- Aeration intensity
- Membrane conditions (extent of fouling)

For all municipal and most industrial applications with systems using MICRODYN BIO-CEL® MBR modules, the chemical cleaning frequencies of membranes are provided in the following table:

Table 6. Membrane Chemical Cleaning Frequencies

Coagulant Addition	Permeate Alkalinity	**Maintenance Cleaning** (# per week)		**Recovery Cleaning** (# per year)	
		Sodium Hypochlorite	Citric Acid	Sodium Hypochlorite	Citric Acid
No	< 70 mg/L	1-2	0	1-2	1-2
No	> 70 mg/L	1-2	1	1-2	1-2
Yes	< 70 mg/L	1-2	1	1-2	1-2
Yes	> 70 mg/L	1-2	1	1-2	1-2

The above recommended chemical cleaning frequencies are typical for most MBR applications. However, in special cases (e.g. high fouling wastewater, low flux operation), the frequency of cleaning and nature of chemical cleaners may be changed. In such cases, please contact your MICRODYN-NADIR representative.

Maintenance Cleaning Procedures

This cleaning can be done for a biomass/process fluid. The standard maintenance cleaning is 60 minutes long. The maintenance cleaning procedure is summarized below:

Table 7. Maintenance Cleaning Procedure

Steps	Procedure
1	Stop filtration of membrane train scheduled to be cleaned. Continue to aerate membranes and recirculate mixed liquor for 10 minutes.
2	Shut off mixed liquor recirculation and isolate membrane tank. Shut off membrane aeration system.
3	Backwash membranes in the train for 540 seconds while dosing appropriate chemical (200 mg/L sodium hypochlorite or 2,000 mg/L citric acid).
4	Backwash membranes in the train for 20 seconds while dosing appropriate chemical (200 mg/L sodium hypochlorite or 2,000 mg/L citric acid).
5	Relax membranes for total of 280 seconds.
6	Repeat steps 4 and 5 for total of 7 backwash and relax cycles.
7	Backwash membranes in the train for 300 seconds (or longer if needed for larger systems) without adding chemicals to flush out the chemicals from piping.
.8	Open the valves that isolate the membrane tank/train.
9	Turn on mixed liquor recirculation pump and membrane aeration for 5 minutes.
10	Resume normal operation.

Recovery Cleaning Procedures

The procedure for membrane recovery cleaning is discussed in this chapter. Note that the recovery cleaning procedure can be completely automated and controlled through PLC allowing all cleanings to be scheduled in advance.

Table 8. Recovery Cleaning Procedure

Steps	Procedure
1	Stop filtration of membrane train scheduled to be cleaned. Continue to aerate membranes and recirculate mixed liquor for 60 minutes.
2	Shut off mixed liquor recirculation and isolate membrane tank. Shut off membrane aeration system.
3	Drain the membrane tank manually or using the recirculation pump.
4	Fill the membrane tank with permeate water using an external pump. Note that other membrane trains are required to stay in operation mode in order to keep the permeate tank full of permeate during this process.
5	Aerate membranes for 60 minutes.
6	Drain the membrane tank again to remove all excess sludge removed from membranes.
7	Fill up the membrane tank with permeate to 80% of the cleaning level.
8	Backwash membranes in the train for 600 seconds while dosing appropriate chemical (2,000 mg/L sodium hypochlorite or 2,000-5,000 mg/L citric acid).
9	Backwash membranes in the train for 20 seconds while dosing appropriate chemical (2,000 mg/L sodium hypochlorite or 2,000-5,000 mg/L citric acid).
10	Relax membranes for total of 120 seconds.
11	Repeat steps 9 and 10 until membrane tank liquid level is 100 % of the cleaning level.
12	Soak membranes in the cleaning solution (2,000 mg/L sodium hypochlorite or 2,000-5,000 mg/L citric acid for 12-16 hours.
13	Continue to backwash membranes without adding chemicals until the membrane tank liquid level is at the cleaning level.
14	Open the valves that isolate the membrane tank/train.
15	Turn on mixed liquor recirculation pump and recirculate mixed liquor for 15 minutes.
16	Turn on membrane aeration and continue to recirculate mixed liquor for additional 15 minutes.
17	Resume normal operation.

4.4 Membrane Aeration

Membrane aeration is a critical part of MICRODYN BIO-CEL® MBR operation. Air bubbles remove the solids accumulated on membrane surface and prevent membrane fouling. The amount of delivered air should match the prescribed design values in this manual; insufficient air may result in membrane fouling.

The air delivered by the blower must be free of oil, dust, condensate and solvents, dust filters in the inlet port of the blower are required. The air temperature must not deviate from the range described in the table below.

Table 9. Diffuser Data

Parameter	Material / Dimensions	Notes
Material Diffuser Membrane	Polyurethane	
Material Diffuser Support Tube	Polypropylene	
Slot Diameter	1.5 mm (0.06 inches)	No standard slot; adapted for MICRODYN-NADIR
Nominal Diameter	63 mm (2.5 inches)	
Clamps	Stainless steel (IN-OX) 1.4301 = AISI 304	
Diffuser Sealing	EPDM	
Connector	¾”	
Distributor Drillhole	45 mm (1.77 inches) with adapter, 40 mm without (1.57inches)	
Inflow Temperature Range	5 to 90 °C (60 °C for BIO-CEL XS) 41 to 194°F (140°F for BIO-CEL XS)	BIO-CEL XS with PVC piping
pH Range	2-11	Same as for membrane module

The required aeration rate is a function of solid mass flux (SMF) and sludge quality. The aeration rate should match those specified in the following table.

Table 10. Aeration Design Parameters for MICRODYN BIO-CEL® Modules

Parameter	**Unit**	**BIO-CEL XL-2**	**BIO-CEL L-2**	**BIO-CEL 416**	**BIO-CEL 208**	**BIO-CEL 104**	**BIO-CEL 52**	**BIO-CEL XS**
# of Diffusers	-	32	8	7	7	4	4	1
Pressure Loss Diffuser @ Recommended Air Flow Rate	mbar	80	80	70	70	70	70	60
	psi	1.16	1.16	1.02	1.02	1.02	1.02	0.87
Blow in Depth @ min. Water Level (Standard Dimensions)	mm	2630	2630	2950	2550	1500	1500	1465
	inches	103.5	103.5	116.1	100.4	59.1	59.1	57.7
Total Pressure Loss at min. Water Level	mbar	343	343	365	325	220	220	206
	psi	5.0	5.0	5.3	4.7	3.2	3.2	3.0
Maximum Aeration Rate in Operation[1]	m^3/h	460	115	105	52.5	60	30	6
	SCFM	268	67	61	30	35	17	3.5

[1] Air flow rate refers to V_n, which is defined at standard conditions according to DIN ISO 2533:1979-12

Note: Changes of the water levels have an impact on the aeration rate!

4.4.1 SMF and Aeration Requirements

The MBR system should always operate under the conditions where there is a balance between solids accumulating on the membranes and solids removed. If there is excess solid accumulation, membranes will sludge up. It is obvious that as MLSS increases more net air is needed to keep the membranes clean. The aeration method has to be designed properly to ensure air is doing the job at a given air flow. The correction discussed here can not include the aerator issues. If aerator is plugged and not functional, the aerator has to be fixed.

The proper parameter to use for MLSS impact is called Solid Mass Flux (SMF) which is a product of membrane flux and MLSS, it can be expressed in units such as g/hr/m^2 of membrane. This is the actual mass flux of solid that is filtered by membrane. Therefore, SMF can be increased not only by increasing MLSS but similarly by increasing the flux. The impact of MLSS is discussed in terms of increase in SMF.

4.4.2 Cyclic aeration

For gross fluxes less than 20 lmh (11.76 gfd) cyclic aeration is possible:

1. The filtration units must be divided into two equal groups and each unit equipped with a proper cyclic valve to accommodate for these cycles. The filtration units may be in two tanks or different modules in the same tank.
2. Use 61 second air on and 61 second air off for total of 122 seconds.
3. Use this protocol only for gross fluxes less than 20 lmh (11.76 gfd).
4. The air flow rate will be the same as currently used in terms of Nm^3 air/h (scfm) per module. During on-time, only half of the membranes will get air and the rest will not. This will cycle through.
5. Recommended valves can be found in Appendix 9.4 Cyclic Valve.

Continuous aeration is recommended for systems with gross fluxes higher than 20 lmh (11.76 gfd).

4.4.3 Diffuser Cleaning

It is important to monitor diffuser performance and clean them regularly to avoid damages to the membranes. Please contact MICRODYN-NADIR for details on diffuser cleaning.

4.5 Antifoam Use

MBR systems may generate foam depending on wastewater characteristics and presence of oil, fat, grease and surfactants. Foam generation is normal and typically occurs at low enough levels that it is manageable without the need for any additional considerations. However, if there is excessive foam, the foam may be removed mechanically or suppressed chemically through the use of antifoam product. It is recommended that the use of antifoam should meet the following main conditions:

1. The antifoam should be effective for the type of foam that is generated in the plant.
2. The antifoam should be compatible with MICRODYN BIO-CEL® MBR modules.
3. The antifoam should not cause fouling of the membranes.

Additional considerations for use of antifoam products include:

- Antifoam are high in BOD/COD and this additional load must be taken into account.
- Antifoam change the small and stable air bubbles into larger bubbles which will in turn, reduce the oxygen transfer efficiency.
- If antifoam product is not biologically degraded, the left over may be found downstream affecting other processes such as RO or ion exchanges.

Most antifoams have the potential to severely foul the membranes. The antifoam products that contain any of the following compounds should not be used in systems using BIO-CEL MBR modules:

- Organic silicone
- Petroleum hydrocarbon (oil)
- Petroleum solvent (light paraffin)
- Polymer additives with molecular weight < 50,000 Daltons (Da)
- Polymer additives with molecular weights of 100,000 to 200,000 Da
- Polymers dissolved or part of a white oil-based products

On the other hand, chemical compounds found within an antifoam product that are desirable include those where the active ingredient is:

- Glycerin with a molecular weight < 5,000 Da
- Polyether polyol with a molecular weight of < 5,000 Da

A list of apporoved antifoam agents can be found in Appendix: Approved Antifoam Agents.

4.6 Achievable permeate quality

MICRODYN BIO-CEL® MBR membranes produce very high permeate water quality. The pore sizes of the BIO-CEL MBR membranes are selected such that all particulate materials (e.g. suspended solids) are rejected by membranes.

However, dissolved and soluble materials such as dissolved organics, dissolved phosphorous or nitrates must be converted to a solid form in order to be removed by the membranes. This can be achieved using biological treatment, precipitation or other methods.

The following table summarizes the permeate quality that can be achieved using BIO-CEL MBR modules for municipal applications considering that the systems are designed, built and operated according to MICRODYN-NADIR guidelines.

Table 11. Achievable Permeate Quality

Effluent Quality Parameter	Expected Permeate Quality	Achievable Permeate Quality
BOD_5	Equal to soluble BOD_5 concentration in mixed liquor	< 5 mg/L
TSS	< 5 mg/L	< 2 mg/L
Turbidity	< 0.5 NTU	< 0.2 NTU,
SDI	< 3	< 3
Total Phosphorous	Equal to soluble BOD concentration in mixed liquor	< 0.1 mg/L
Ammonia	Equal to soluble ammonia concentration in mixed liquor	< 0.1 mg/L
Total Nitrogen	Equal to soluble TN concentration in mixed liquor	< 3 mg/L
Bacteria Removal	> log 6	> log 6
E.coli	> log 5	> log 5
Fecal coliform Removal	> log 5	> log 5
Total coliform Removal	> log 5	> log 5

Notes:

1. BOD_5 level is achievable only with appropriate biological system design and temperature.
2. Ammonia level is achievable only with appropriate biological system design and temperature.
3. Total nitrogen level is achievable only with appropriate biological system design and temperature.
4. Total phosphorous level is achievable with appropriate coagulant addition system.
5. The standard analytical method used for measuring total suspended solids (TSS) lacks precision at < 5 mg/L. A more precise method is to use continuous online turbidity measurement. This is more accurate for the low turbidity ranges expected for permeate quality.
6. Sampling procedures, volume and location to be determined in detail.
7. Accurate microbiological results require weekly (at least) permeate piping disinfecting and proper permeate piping design.

4.7 Mechanical Cleaning Process (MCP)

The MICRODYN BIO-CEL® MBR membrane module may also be cleaned mechanically through the use of the patented BIO-CEL® MCP (Mechanical Cleaning Process), to help reduce operating costs. This innovative process using inert, organic material (MCP granulate), supported by cross-flow aeration, reduces the formation of a fouling layer. Long term experiences show, that a chemical reduced operation is possible, but there is still a need of regular chemical disinfection of permeate piping.

Continuous Membrane Cleaning During Operation of the BIO-CEL MBR Module

The MCP granulates are added directly into the activated sludge. The airflow induced by the module aeration system pushes the MCP granulates up between the membrane sheets. As the MCP granulates rise, the membrane area is continuously cleaned through the direct contact of the granulates with the sludge on the membrane surface.

The fouling layer formed during the filtration process may be removed reliably without compromising the functionality of the membrane. In the downstream area outside the membrane modules, the current causes the granulates to sink back to the base of the module where it enters again into the upstream flow. The MCP granulates have been designed for permanent use. They are retained in the filtration tank by suitable separation systems.

Advantages of retaining MCP granulates in the filtration tank:

- Reduced costs for MCP granulates due to lower mixing volume (compared to having MCP granulate in aeration tank and filtration tank)
- The crossflow aeration or a mixer that prevents granulates from settling at the bottom of the tank may be smaller as the membrane aeration is providing the majority of the required crossflow.

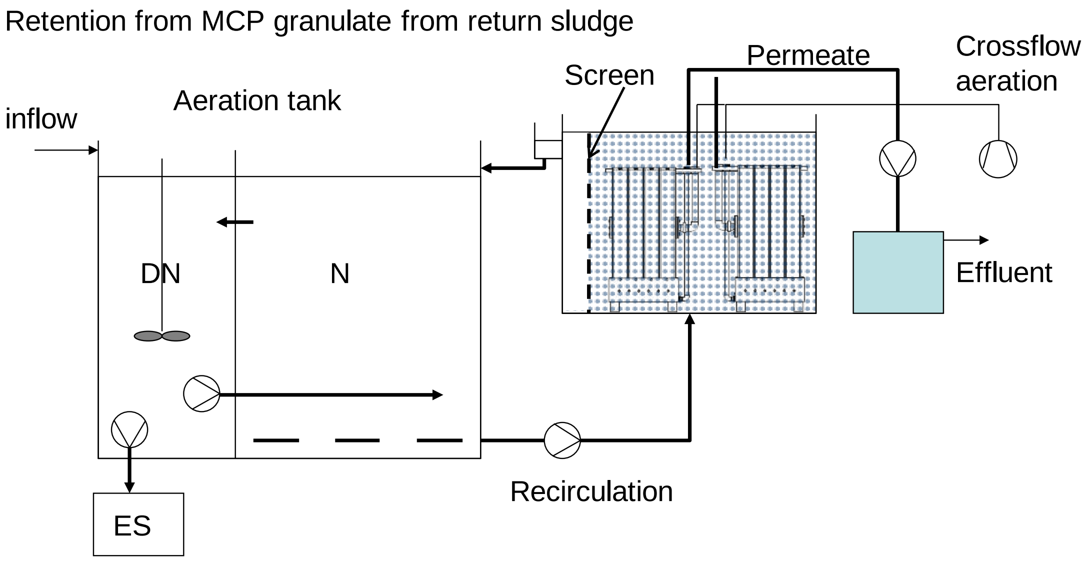

Figure 2. MCP granulat in filtration tank

Retention of MCP from Return Sludge

To prevent the MCP granulates from entering the return sludge stream, a screen for the filtration tank is required. MICRODYN-Nadir recommends the following design:

- The screen should be made of a stainless steel wedgewire or bar screen type installed with a slight slope.
- An air diffuser at the foot of the screen ensures a constant cross-flow over the screen surface and keeps the screen free of blocking by sludge particles. MICRODYN-NADIR recommends membrane tube diffusers with relatively big slots (it is highly recommended to avoid using coarse bubble diffusers since blocking of diffusers is expected).
- The screen must be able to withstand a possible blockage and the resulting mechanical stress because of a level increase before the screen.
- To protect screens from mechanical damage, MICRODYN-NADIR recommends automated control of the level difference at the screen to set levels:
    - Alarm level: screen is getting blocked and has to be cleaned
    - Shut off level: protect screen from irreversible damage by stopping the operation in the affected tank

- Steel grades: 1.4301/304 or 1.4404/316L & 1.4571/316Ti
- Screen slope: 0 - 3°
- Screen gap size: 2.5 - 3.0 mm (0.09 - 0.12 inches)
- Total opening ratio: ≥ 50%
- Effective screen size:

$$A_{screen} = \frac{Q_{Sludge}}{30}$$

A_{Screen} = effective screen size [m²]

Q_{Sludge} = sludge throughput [m³/h], e.g. return sludge from filtration tank to biology

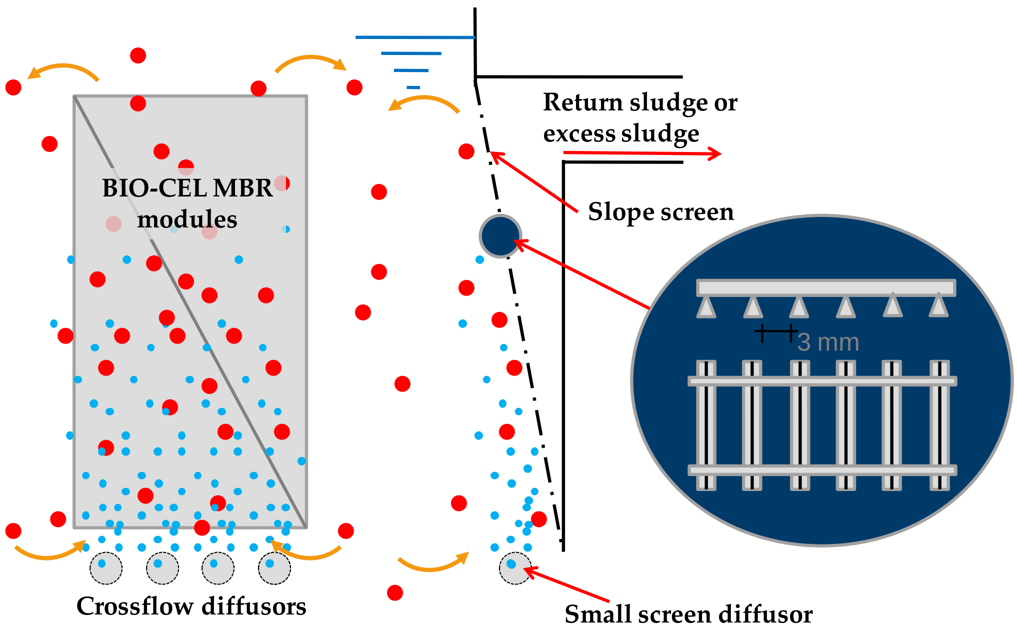

Figure 3. Example schematic of MCP operation in the MBR plant

Screen diffusers

- Gap between diffuser and screen: 20 – 30 mm (0.79 – 1.18 inches)
- Membrane tube diffusers: slots with >1mm (>0,04 inches)
- Length of diffuser perforation: same as screen length
- Screen diffuser air flow rate: Vn = 10 - 15 m³/(h*m diffuser length)
- The air flow rate of the screen diffusers must be independent from other operation equipment; changes in other parts of the plant should not affect the air flow rate of the screen diffusers.

Tank design

- MCP granulate concentration: 4 – 10 kg per m³ of activated sludge
- It is important to avoid any dead zones in the tank which may cause sedimentation of MCP beads.
- If a free space is available inside the tank, appropriate mixing needs to be performed.
- It is recommended to use the RAS inflow to obtain additional mixing. The RAS sludge may be distributed over the length inside the filtration tank by a peforated pipe.

5 Membrane Tank & Train design

5.1 General Filtration Line Design

The membrane filtration process may be designed according to one of the following configurations.

5.1.1 External Configuration of the Module inside the Filtration Tank

- Modules installed inside the filtration tank
- Recycle feed control
- Module(s) do not need to be removed from the tank for recovery cleaning

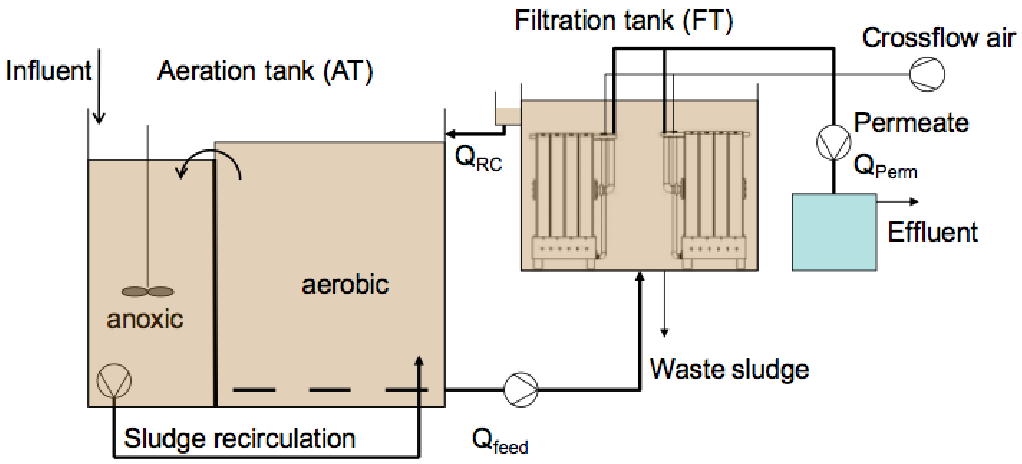

Figure 4. External configuration

5.1.2 Gravity-Fed Configuration of the Module inside the Filtration Tank

- Permeate production is gravity controlled
- Backwash of modules by gravity flow (alternatively by pump)
- Pump necessary for filling permeate tank
- Module(s) do not need to be removed from the tank for recovery cleaning

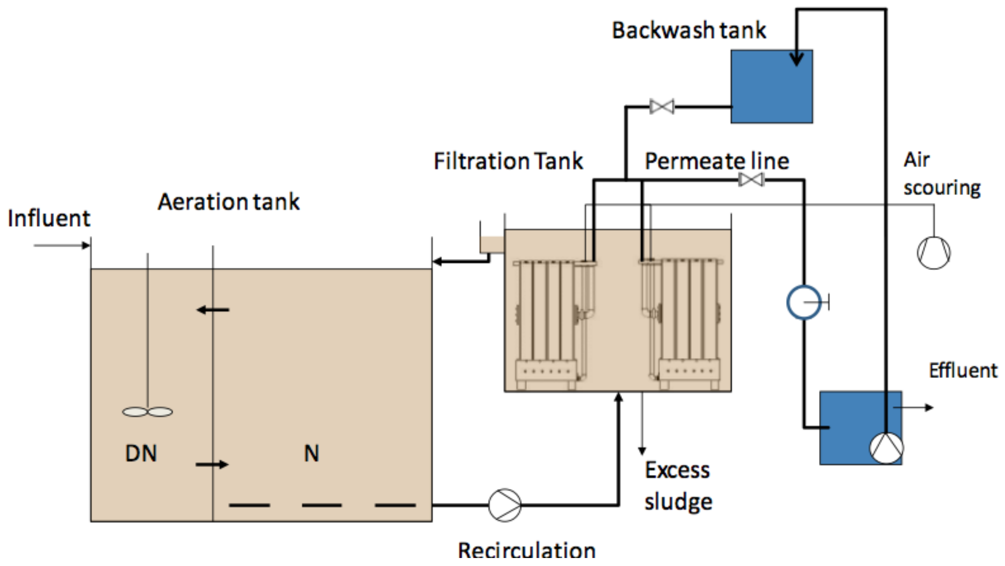

Figure 5. Gravity flow

5.1.3 Internal Configuration of the MICRODYN BIO-CEL® Module inside the aeration tank

- Modules installed inside the aeration tank
- Maximum oxygen transfer
- Low energy demand
- Module to be removed for recovery cleaning

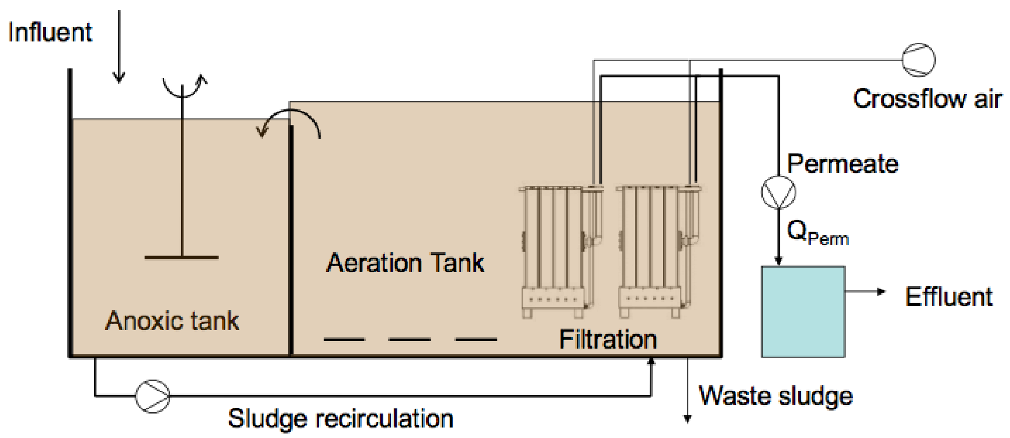

Figure 6. Internal configuration

5.2 Mixed Liquor Entrance & Recirculation Outlet

The membrane tank should include features designed to prevent damage to the membranes when filling or feeding the tank with mixed liquor. The liquid must not directly impact the membrane or module frame. Instead, the liquid must first impact a tank wall, tank floor or a deflector plate in order to adsorb the kinetic energy prior to contacting the membranes or modules. This is especially important for all MICRODYN BIO-CEL® L installations.

In cases where feed enters at the beginning of the tank, it is highly recommended to have a feed sump running along the short length of the tank at the bottom of the tank. Feed may also enter from the top through a distribution channel overflowing from the bioreactors.

It is important to prevent a short circuit flow from the mixed liquor entry point to the recirculation outlet point. In order to achieve this, the two should always be on opposite ends of the tank.

5.3 "Pump-To" Versus "Pump-From" Designs

Typically, the transfer of mixed liquor between bioreactors and the membrane tanks is achieved by pumping in one direction and flowing by gravity in the other direction. Given this situation, the designer must choose whether to:

- "Pump to" the membrane tanks and return to bioreactors by gravity
- Flow to the membrane tanks by gravity and "pump from" the membrane tanks back to the bioreactors

Several considerations for each of these options are given below:

- "Pump-To" also known as "Feed Pump" option:
  - The liquid level in the membrane tanks is higher than the level in the bioreactors
  - A higher pump flow is required (e.g. the pump needs to supply the recycle flow and permeate flow).
- "Pump-From" also known as "Return Pump:
  - The liquid level in the membrane tanks is typically lower than the level in the bioreactors
  - A lower pump flow is required (e.g. the pump needs to supply the recycle flow only). There is a risk of emptying the membrane tank in case of no flow from the bioreactor and pump switch-off failure.

The optimal design regarding in which direction to pump the mixed liquor will vary from plant to plant. Factors such as plant layout, grading, site topography, retrofit, etc. will influence which design is preferred. Considering the lower cost of pumping and if the plant layout allows for this, the "pump-from" option is the preferred method.

5.4 Filtration Tank Cover

Foliage or other materials entering the system may block the space between the membrane sheets. Sludge circulation, cross-flow and oxygen supply will be inhibited due to the blocked channels. The embedded activated sludge will be dewatered by further filtration and will thicken. The blocked membrane surface will become inactive and will not be available for filtration. Additionally, blocked channels may lead to structural damage to the membrane sheet.

In order to avoid this potential damage, all tanks (not only the filtration tanks) and channels should be covered to prevent entry of foliage or other materials that may block the cross-flow channels or damage the membranes. Any materials from the plant assembly (e.g. cable clips) and sharp particles which could block the cross-flow channels or damage the membranes must be removed and it must be ensured that no particles ≥ 2 mm are in the tanks. A cleaning of the filtration tank once a year is strongly recommended.

5.5 Membrane Tank Sloped Bottom & Clearances

There are several designs for sloping the bottom of the membrane tank. The most common designs include:

1. Gradual slope from the feed end to the reject end with a simple sump or trench at the reject end; trench runs along the short end of the tank (along the tank wall).
2. Length-wise trench down the center of the tank bottom; floor slopes from each side wall to the center trench.
3. Length-wise trench down one side of the tank bottom; floor slopes only from the opposite wall; this design is particularly simple to build as two tanks are side by side and the common wall is located in the sump.

The more common option for MBR is gradual slope from feed end to the reject end. MICRODYN-NADIR recommends this option for the following reasons:

- Least expensive to build since it requires the least amount of concrete forming.
- Mixed liquor feed can be used to flush solids that collect at the bottom of the tank. With the length wise trench designs, the feed would naturally flow into the trench and the solids at the opposite end would not be effectively flushed out.
- The drain trench or sump may also be used for RAS recycle (if RAS overflow out of the membrane tank is not employed).

The disadvantage of the gradual slope design is that on longer trains, the clearance under the module becomes significant and more excavation is required during construction and more chemicals are needed during intensive cleanings.

The membrane aeration provides significant mixing under the modules. The recommended clearances are as follows:

1. The minimum and maximum distance between the bottom of the module frame and the floor of the tank varies for different module types and can be seen in **Table 12**.
2. The recommended slope is 2%. Therefore, on extremely long tanks where a 2% slope would result in too high clearance under a module, the length-wise trench should be considered.
3. The modules must always be levelled inside the tank. The maximum deviations are listed in **Table 13**.

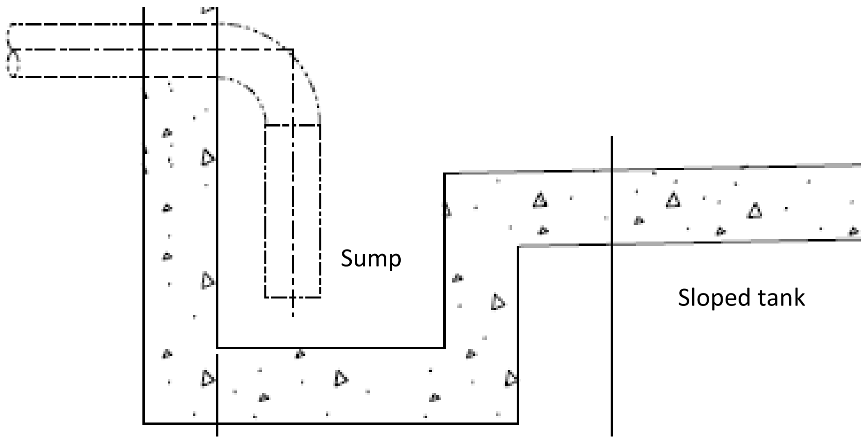

Figure 7. Sump pit and sloped tank

5.6 Membrane Tank Sizes & Module spacing

To ensure proper aeration and mixing of sludge within the tank with proper flow pattern, the membrane tank should be designed with certain limitations as follows. The table below shows the required operating levels in the membrane tank for MBR applications using concrete membrane tanks. For other cases, please contact MICRODYN-NADIR for assistance.

Table 12. Membrane Module Clearances

Parameter	Units	BIO-CEL XL-2	BIO-CEL L-2	BIO-CEL 416	BIO-CEL 208	BIO-CEL 104	BIO-CEL 52	BIO-CEL XS
Top clearance	mm	250 - 1000	250 - 1000	400 - 800	250 - 800	200 - 400	200 - 400	155 - 400
	inches	9.8-39.4	9.8-39.4	15.7-31.5	9.8-31.5	7.9-15.7	7.9-15.7	6.1-15.7
Ground clearance	mm	250 - 600	250 - 600	400 - 800	200 - 800	200 - 400	200 - 400	155 - 400
	inches	9.8-23.6	9.8-23.6	15.7-31.5	7.9-31.5	7.9-15.7	7.9-15.7	6.1-15.7
Module height with feet & without eyelets	mm	2675	2675	2963	2763	1563	1563	1515
	in	105	105	117	109	62	62	60
Tank footprint	m^2	≥ 12.25	≥ 2.9	≥ 3.1	≥2.2	≥ 1.8	≥ 1.2	≥ 0.54
	ft^2	≥ 131.8	≥ 31.2	≥ 33.4	≥ 23.7	≥ 19.4	≥ 12.9	≥ 5.8
Ground coverage	%	47	57	51	41	53	42	18
Maximum operation level	mm	3675	3675	3800	3350	1950	1950	1915
	inches	144.7	144.7	149.6	131.9	76.8	76.8	75.4
Minimum operation level	mm	2925	2925	3400	3000	1750	1750	1670
	inches	115.1	115.1	133.9	118.1	68.9	68.9	65.7

Notes:

1. Typically, trains are recommended to have one row of modules when there are up to 12 modules per train, and two rows of modules (twin module) when there are 10 or more modules per train.
2. Too low top clearance may cause sludge accumulation inside the module, too high top clearance increases pressure loss for aeration.
3. High ground clearances may cause sedimentation issues.
4. Feet are not included in the scope of supply of BIO-CEL® XL-2, BIO-CEL® L-2 and BIO-CEL® 416 modules.
5. Minimum tank footprint is calculated considering minimum side clearances for each module.
6. Ground coverage is the module footprint divided by the tank footprint.
7. The maximum operation level may be adjusted to allow the required head for gravity operation at the discretion of MICRODYN-NADIR
8. All operation level values are in reference to the distance above the tank floor at the shallow end of the membrane tank.
9. Dimensions simplified; exact dimensions according to approved drawings. Clearances may be reduced.

5.7 Liquid Operating Levels between Different Trains

When multiple tanks or trains are aerated using the same common membrane aeration blower, it is critical that the operating level in different trains is the same. If the liquid levels are different in different trains operating from the same air header pipe, the air will go to the diffusers that have the lower liquid level on top of them (e.g. lower resistance). This will cause uneven air distribution. This is not an issue if each membrane train has its own dedicated air blower, then this is not an issue.

For a common air header feeding multiple trains, it is critical to ensure:

- The liquid level in all tanks remain the same over time.
- Hydraulically connect all membrane tanks by using a common feed channel and submerged or partially submerged sluice gates. Make sure the gates are sized large enough to avoid any significant head losses between channel and membrane tank.
- For the pump-to option using an overflow weir, make sure the crest of the overflow weir is set at the same level for all tanks and liquid flows to all tanks at the same rate.

5.8 Mixed Liquor Recirculation

If membranes are installed in a separate tank, mixed liquor must be recirculated back to bioreactors. This may happen either by pumping from the membrane tank or into the membrane tank. The flow of recirculated activated sludge (RAS) may be between 3 to 6 times that of the membrane permeate flow.

The RAS flow rate in MBR system depends on two factors:

- Solid mass flux to the membranes and required RAS flow to ensure MLSS build up in membrane tank is within acceptable range
- Total Nitrogen removal considerations

6 Modules Installation Options

There are different options for mounting MICRODYN BIO-CEL® MBR modules in the tank. In all cases the modules must be fastened in a way that they cannot move and that the minimum ground clearance and minimum head on top of the modules meet recommended guidelines.

6.1 General Information on Module Installation

Lateral Pressure / Application of Force on Frame & Piping

All lateral pressure on the body of the module frame/structure is to be avoided. The frame is not intended to be load bearing.

The installation of the membrane equipment must be completed without any force on the frame or the air and permeate piping.

The installed equipment must rest comfortably within the basin, and all attachments must be accurately aligned, avoiding pressure on the equipment.

Lateral pressure on the connections or the associated pipe can cause breaches which will result in contamination of the membrane or diffuser unit and the permeate liquid.

Leveling the Modules

For all installation options, a proper leveling of the module is mandatory. The following specifications must be considered:

Table 13. Horizontal Deviation

	Units	BIO-CEL XL-2	BIO-CEL L-2	BIO-CEL 416	BIO-CEL 208	BIO-CEL 104	BIO-CEL 52	BIO-CEL XS
Maximum Horizontal Deviation	mm	10	5	5	2,5	5	2.5	2.5
	inches	0.4	0.2	0.2	0,1	0.2	0.1	0.1

The above specifications may be met by:

- Leveling the tank floor
- Leveling the module with additional leveling feet at the module legs
- In both cases the leveling equipment must be able to bear the maximum possible load of the modules.
- Hanging the modules.

6.2 MICRODYN BIO-CEL® - Installation in Filtration Tank

If modules are installed in a separate filtration tank, the tank should be big enough to install the modules and allow for the correct circulation of cross-flow aeration (please refer guidelines).

When having a separate filtration tank, fixed installation is the preferred installation method. Once the modules are installed, they remain there until the end of their lifetime. That means for any inspection or maintenance reason, the filtration tank must be emptied. If the modules must be removed during their lifetime for servicing, it is important to have flanges in the air and permeate lines above the water level.

The modules must be fixed in the tank to prevent lateral movement and floating. MICRODYN-NADIR recommends hanging module fixation.

Important note for all installation options: The air hose has to be fixed to the tank wall to prevent damage to the diffuser unit.

6.2.1 Option 1 – Tank Wall Fixation with Fixed or Adjustable Legs

Fixed Legs

Fixed legs, or standard legs, are used for this option of module installation. The additional metal rods slide into the existing hollow pipe and are locked using a lock bolt. The module must be centered, levelled and adjusted inside the tank. Once leveling has been completed, the appropriate wall brackets may be marked and installed in the wall by using the metal rod as guiding.

Lock the metal rods with the bracket and the provided bolts. Make sure the module is not hanging from the wall brackets which may introduce additional stress.

Refer to **Figure 8** for wall bracket installation.

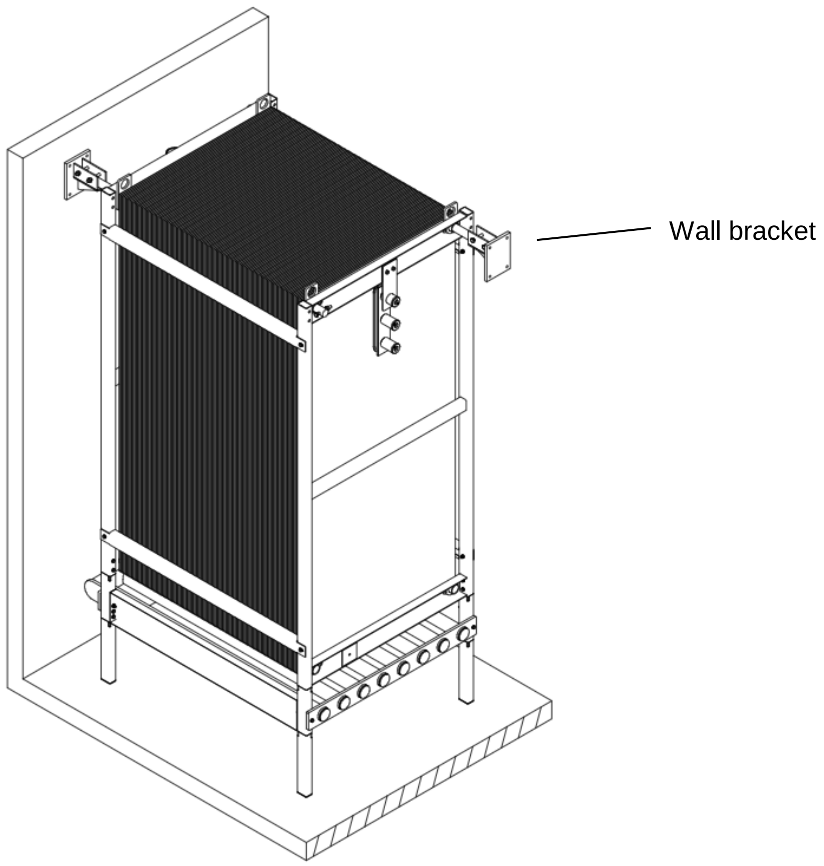

Figure 8. Tank wall fixation with fixed legs

Adjustable Legs

Alternatively, adjustable legs may be used to level the module easily without additional parts. The additional metal rods slide into the existing hollow pipe and are locked using a lock bolt. The module must be centered, levelled and adjusted inside the tank. Once leveling has been completed, the appropriate wall brackets may be marked and installed in the wall by using the metal rod as guiding.

Lock the metal rods with the bracket and the provided bolts. Make sure the module is not hanging from the wall brackets which may introduce additional stress.

6.2.2 Option 2 – Lifting & Guiding System for Tank Wall Fixation

Fixed Legs

Standard legs are used for this option.

The additional guide brackets should be installed to help guide the module. The guide bracket is installed on top and bottom of the module structure with an L-angle bar and angle bar brackets.

Refer to **Figure 9** for wall-guiding installation.

The module must be centered, levelled and adjusted inside the filtration tank. Once the leveling has been completed, the guide pole should be inserted into the brackets. The guide pole should be adjusted and levelled before fixing into the wall using module guide. Once the guide poles and bracket have been adjusted and fixed, a locking mechanism must be installed to prevent the module from floating.

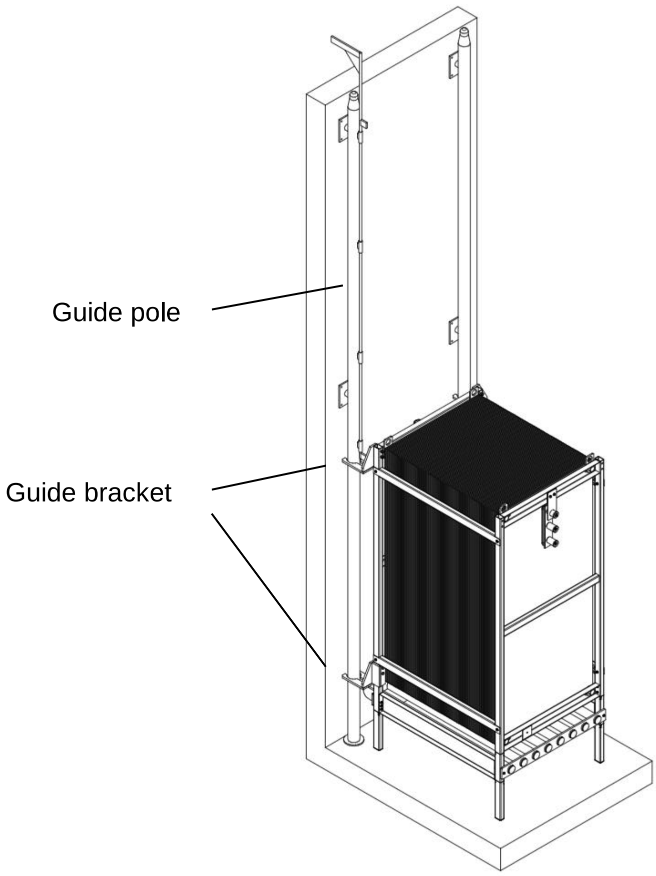

Figure 9. Lifting and guiding system with fixed legs

Adjustable Legs

Adjustable legs adjustable legs are used to level the module easily in this option.

The additional guide brackets should be installed to help guide the module. The guide bracket is installed on top and bottom of the module structure with an L-angle bar and angle bar brackets.

The module must be centered, levelled and adjusted inside the filtration tank. Once the leveling has been completed, the guide pole should be inserted into the brackets. The guide pole should be adjusted and levelled before fixing into the wall using module guide. Once the guide poles and bracket have been adjusted and fixed, a locking mechanism must be installed to prevent the module from floating.

6.2.3 Option 3 - Hanging

A lifting and hanging frame is fastened to the top of the module and secured with bolts.

Refer to **Figure 9** for hanging installation.

The module must be centered, levelled and adjusted with the hanging frame outside the filtration tank. Once the leveling has been completed, the should be inserted into the filtration tank and fastened to the wall brackets.

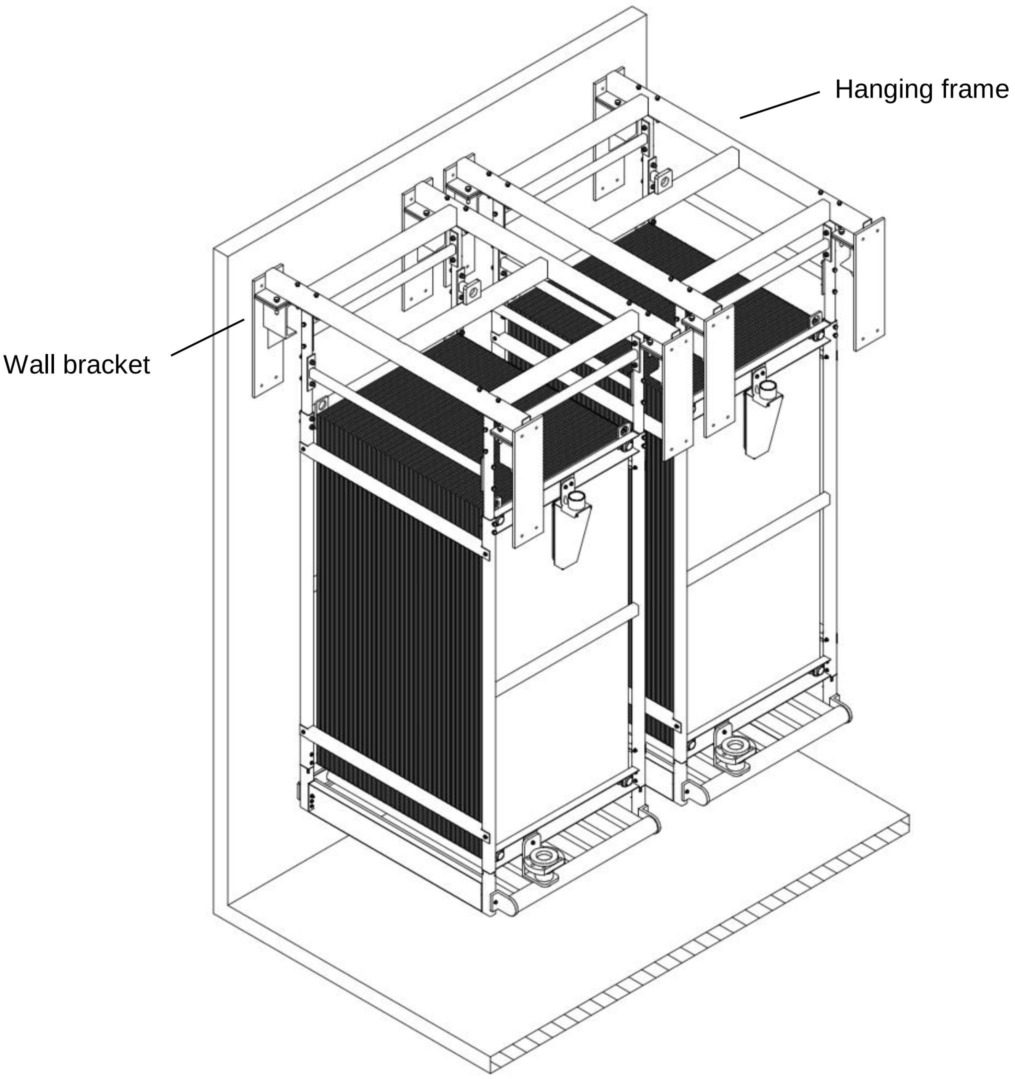

Figure 10. Hanging installation of two modules

7 PLC Description & Instrumentation

This chapter provides a standard description for a programmable logic controller (PLC) for MICRODYN BIO-CEL® MBR operated in municipal and industrial wastewater. The target groups are the designer and programmer.

This chapter contains recommendations to design PLC of a membrane bioreactor (MBR) consistent of biology and filtration tank. Please note that this is not warranty related and all information needs to be validated for the individual process and cannot be directly adopted.

The design of special industries and for gravity flow operation may vary, but in general these PLC guidelines cover the most important parts of PLC design.

Applicable Documents

- MICRODYN BIO-CEL® Operation&Maintenance Manual *(will give you and idea of maintenance and operation and some parts can be beneficial to understand this document better)*
- MICRODYN BIO-CEL® Standard Piping & Instrumentation Diagram (P&ID) *(in addition the individual P&ID it is a help for designing a plant and is a basis for this document)*
- MICRODYN BIO-CEL® Operation Sequence Control Chart (OSC) *(directly related to this document and is required to understand this document).*

Please note that the following parts are NOT included in this chapter:

- Detailed PLC of gravity flow application
- PLC of total wastewater treatment plant
- Details of how to control biology (in responsibility of system integrator)
- PLC for individual project design

In the documentation, the Programmable Logic Controller is referred to as the PLC. The PLC follows specific steps to automatically control valves, pumps and other devices during the operating states of the treatment plant. These steps are listed and described in the OSC.

The PLC provides:

- Automated control of the BIO-CEL equipment. All the programming for the control of the BIO-CEL plant is stored in the PLC.
- Modes are a series of steps the tank follows to perform various operations, such as a cleaning. A specific mode discussed in this document is shown in capital letters, such as MAINTENANCE CLEANING. Buttons displayed on the HMI (Human Machine Interface) screen that the operator can press to initiate a mode or other operation are shown with the first letter capitalized. For example, one button that is used to put a tank to OFF mode is the OFF button.
- Set points, alarms, and calculated parameters are assigned tags in the PLC code. When tags are used in the Control Narrative, they are identified by an alpha-numeric label.
- The Standard Operational Parameters are adjusted in the HMI for plant control and are listed in Table 22. These parameters are reffered to in this document as R1, R2 etc.
- Specific data is stored for plant monitoring and it is also recommended to store manual taken offline data in the PLC.

7.1 Instrumentation

7.1.1 TMP Measurement

Transmembrane pressure (TMP) is an extremely important operational parameter that must be continuously monitored. We recommend using a precise digital gauge that can continuously provide accurate measurements. Calibration according to the manufacturer's recommendations is very important for the safe operation of the membrane module. The PLC should be programmed to ensure that the pressures never exceed the critical values that may lead to membrane damage. Effects of pressure losses in the piping system should also be considered. Therefore, the probe should be installed as close to the modules as possible to measure the negative pressure accurately.

The TMP signal should be transferred to the PLC every second. The TMP measurement should be recorded at least once per minute.

Note: Changes on the levels of water in the tank may have an impact on the TMP reading.

7.1.2 Flow Measurement

Other important parameters of the system include permeate and air flow.

Permeate Flow

The flow and the membrane area determine the system flux. The flow sensor monitors the amount of water the system is treating and can indicate potential issues within the system if design values are not achieved. We recommend using electromagnetic flow meters to ensure the most accurate readings are collected. Please ensure that the chosen device can measure both flow directions (filtration and backwash). Both flow directions must be transferred to the PLC with the correct prefix (+/-).

Air Flow

Air flow measurement for each individual module is important to ensure that the maximum aeration rate is not exceeded at any time and to monitor the equal flow distribution throughout the system. We recommend using digital air flow meters.

The flow measurements should be continuously recorded and reported in coordination with the TMP.

7.1.3 Temperature & pH Measurement

The temperature affects various system parameters and must be continuously monitored. The temperature affects viscosity which in turn has an effect on sludge filterability. An accurate temperature is imperative when setting flux levels and calculating costs associated with energy use.

It is important to be able to measure the pH in the MBR tank as well as the pH in the pipes during chemical cleanings. To monitor both, the sensor should be installed between the membranes and the dosing point of the chemicals. In this case, the permeate quality represents the pH in the MBR tank.

7.1.4 Turbidity Measurement

While a turbidity measurement of the effluent is not mandatory to ensure a stable process, it is an accurate and simple way to determine the separation performance of the system. High turbidity in the effluent indicates that there may be leaks. It is highly recommended to stop the system and investigate the source of failure immediately. For best results it is recommended to install the turbidity sensor after the venting tank.

7.1.5 Level Measurement

Level measurement is essential for the operation of the pumps and blowers. Level sensors used in tanks with mixed liquor should be hydrostatic or ultrasonic.

7.2 Tank and Permeation Equipment

A schematic representation of the process is illustrated in **Figure 11**. Please note that this schematic representation is based on the standard P&ID of MICRODYN-NADIR and nomenclature is taken over. **Figure 11** is a simplified illustration of the MBR process, whereas an entire plant consists of several filtration lines with several membrane modules included in each filtration line.

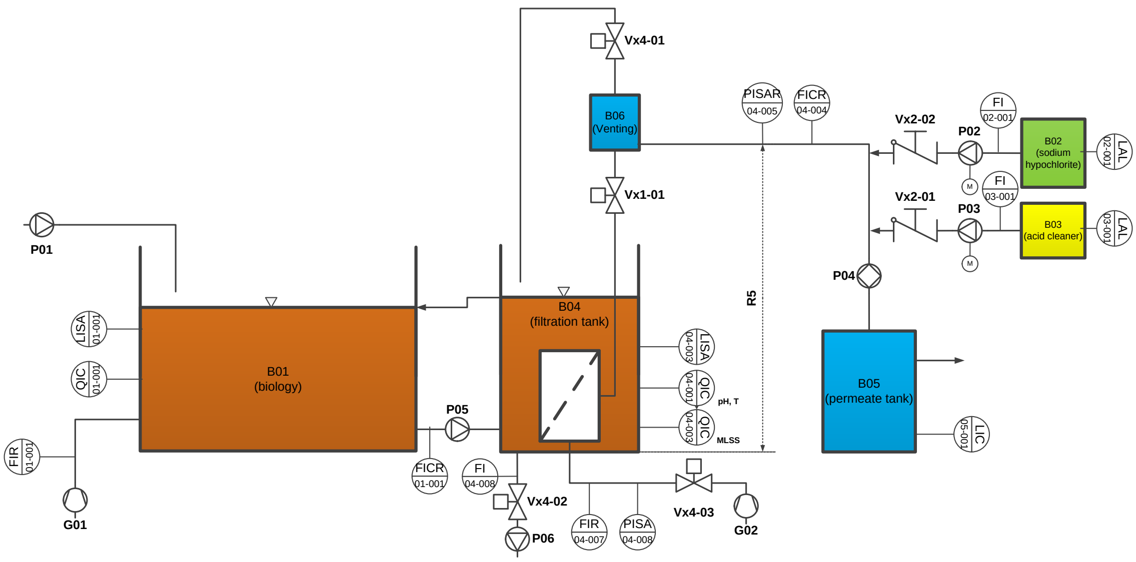

Figure 11. Schematic representation of MICRODYN BIO-CEL® MBR process

A list of all all components and instruments according to **Figure 11** is given in the tables below.

Table 14. Components (pumps, blower and valves) according to **Figure 11**

Nomenclature	Description
G01	Blower for biology
G02	Blower for filtration tank
P01	Inflow pump to biology (project specific)
P02	Dosing pump for chemicals (alkalinic cleaner)
P03	Dosing pump for chemicals (citric cleaner)
P04	Process permeate pump (reversible for filtration and backwash)
P05	Recirculation pump (in filtration tank, not required if membrane modules are installed in biology)
P06	Drain pump (removal of excess sludge)
Vx1-01	Permeate header valve to permeate pump (open/closed)
Vx2-01	Valve chemical line (citric cleaner)
Vx2-02	Valve chemical line (alkalinic cleaner)

Nomenclature	Description
Vx4-01	Venting eject valve (open/closed)
Vx4-02	Filtration tank drain valve
Vx4-03	Membrane aeration valve

Table 15. Instruments according to **Figure 11**

Nomenclature	Description	Unit
FI 02-001	Flow control chemical pump P02	l/h (gpm)
FI 03-001	Flow control chemical pump P03	l/h (gpm)
FI 04-006	Flow Control sludge draining	Nm^3/h (gpd)
FICR 01-001	Flow Control Recirculation	Nm^3/h (gpd)
FICR 04-004	Flow Control Permeate	Nm^3/h (gpd)
FIR 01-001	Flow control process air biology	Nm^3/h (SCFM)
FIR 04-007	Flow Control crossflow aeration	Nm^3/h (SCFM)
LAL 02-001	Low level alarm B2 (min)	-
LAL 03-001	Low level alarm B3 (min)	-
LIC 05-001	Level measuring min for P04 (min)	meter (feet)
LISA 01-001	Level measuring biology (min and max)	meter (feet)
LISA 04-003	Level measuring filter tank (min and max)	meter (feet)
PISA 04-008	Pressure sensor for crossflow pipe filtration tank	mbar (psi)
PISAR 04-005	Pressure indicator permeate pipe (overpressure/vacuum)	mbar (psi)
QIC 01-001	Oxygen sensor	mg/l
QIC 04-001	pH and T sensor	-; °C (°F)
QIC 04-003	MLSS sensor	g/l

7.2.1 Operational Modes

The tank has separate mode buttons. There are several modes for the tank, these modes are: OFF, SHUTDOWN, POWER OFF, STANDBY, VENTING, BACKWASH, RELAXATION, FILTRATION, MAINTENANCE CLEANING, RECOVERY CLEANING and NEUTRALIZATION.

Using the tank mode buttons on the HMI, the operator can put the tank into a different mode. There are some interlocks present to prevent the user from proceeding to one mode from another. These interlocks are for membrane protection. Not all modes are selectable. Consult the OSC for further details on the modes.

For the tank to operate automatically the operator needs to have all devices set to AUTO and ON button for the tank. Pressing the ON button places the tank into VENTING and then into STANDBY mode. When a start trigger is active, the tank proceeds to FILTRATION and then either BACKWASH or RELAXATION modes.

The tank will continue in the FILTRATION cycle, alternating between FILTRATION and either BACKWASH or RELAXATION modes, until the plant flow demand to treat wastewater decreases placing the tank to STANDBY. A scheduled MAINTENANCE CLEANING will automatically interrupt the production cycle. An alarm may also place a tank to STANDBY or SHUTDOWN.

The operator may interrupt the FILTRATION cycle by pressing either the MAINTENANCE CLEANING or BACKWASH button. The tank will proceed to the selected mode once the resources are available. There should be interlocks preventing more than one tank from entering the same mode at the same time. Consult the OSC for details on the interlocks.

It is the responsibility of the operator to ensure that if the OFF button is pressed when a tank is in the MAINTENANCE CLEANING or RECOVERY CLEANING modes, the membrane tank's contents are suitable for a tank to proceed to another mode. Neutralization may be required, or the membrane tank may need to be drained.

Manual operation (ON/OFF/MANUAL mode) is just recommended for experienced operational staff via the PLC. All devices are switched manually. Initial position is OFF.

CAUTION

REQUIREMENTS

1. ALL SAFETY REQUIREMENTS GIVEN FOR AUTOMATIC OPERATION NEEDS TO BE CONSIDERED FOR MANUAL MODE.
2. DOUBLE CHECK OF SETTINGS OF MANUAL MODE TO THE OSC SEETINGS FOR ALL MODES.

7.2.2 Plant Flow Demand

There are two favored options to control the process permeate pump and operation of the filtration lines. Permeate flow can bei either controlled by level in the biology or by influent flow signal. A control based on biological level is simpler. But in case of highly varying flow conditions (like high peak flow factors or small buffer capacity), a control based on influent flow may be favoured. The advantage of influent flow signal control is that the systems reacts sooner especially in case of peaking conditions.

7.2.2.1 Control based on Biological Level

The process permeate pump and operation of the filtration tank can be controlled by level in biological tank (see **Table 16**). At first, the permeate process pump ramps up to low flow conditions at minimum level in biology. Secondly, When the optimum level is exceeded, permeate process pump ramps up to medium flow. Thirdly, the peak flow is attained as soon as the peak level in biology is exceeded.

Table 16. Flow level dependent on level in biology

Level in Biology	Permeate Process Pump
R16 Min. level biology	Low flow
R17 Medium level biology	Medium flow
R18 Peak level biology	Peak flow

The communication of several lines is possible in different ways. However, it needs to be avoided that the maximum level in biology is exceeded.

For smooth operation of the filtration lines, all lines go to low flow at first. Afterwards all lines to go medium and then finally to peak flow condition. A timer is set when the next line goes online. At the same time the flow needs to be maintained during this time.

For energy efficient operation, it is possible to first ramp up one line from low to medium and then to peak flow at first. If the level is still increasing, the next line goes online.

7.2.2.2 Control based on Influent Flow Signal

The influent flow signal is used in the calculation of the plant flow demand, which controls the speed of the process permeate pump. As the influent flow increases the plant flow demand (or permeate flow) increases, causing the process pump to speed up. To prevent standby and overflow conditions, the average level in the filtration tank is used to trim the plant flow demand.

Level control is accomplished with proportional control. The PLC performs these calculations. The plant flow demand is the net permeate flowrate required from the tank and does not include additional permeate the tank produces for non-filtration operations, such as BACKWASH. The production cycle for a tank is FILTRATION followed by either BACKWASH and/ or RELAXATION.

The trim flowrate, which is a calculated flow, is added to or subtracted from the influent flowrate according to the average level in the filtration tank and the difference from the level set point. As the level increases above the set point in the filtration tanks, the trim increases causing the overall plant flow demand to increase.

When the plant flow demand increases, the process pump for the tank operation is ramped up to increase the plant permeate production which brings the level down in the filtration tanks. Conversely, if the filtration tanks are below the set point, the calculated trim flowrate is a negative flow and the overall plant flow demand decreases. The process pump is ramped down, decreasing permeate production, and the filtration tank level increases because of the decreased permeate production. In general, the minimum level in the filtration tank needs to be maintained and fluctuations in level needs to be reduced to a minimum.

The flow set point for tank with a manual flow set point is subtracted from the plant flow demand which includes the level trim. This value becomes the net filtration flow set point for the tank. A correction factor is calculated to account for the time when the tank is not producing water (i.e. RELAXATION or BACKWASH) and to produce additional water required for backwashing the membrane. The net filtration flow set point multiplied by the correction factor is then used to calculate the instantaneous flow set point for the tank. This value controls the process pump speed through the flow PID loop.

A flow setpoint may also be entered for each tank manually. The supervisor can do this by setting the FILTRATION flowrate on the HMI. The PLC will maintain the entered FILTRATION flowrate or PLC calculated FILTRATION flowrate up to a maximum Trans-Membrane Pressure (TMP) or a minimum filtration tank level.

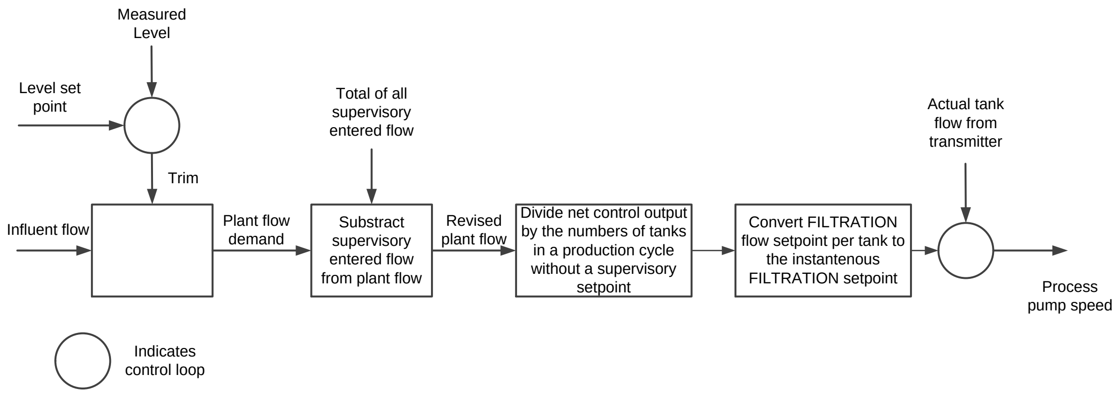

Figure 12. Influent Flow, Level Control & Permeate Flow Control Chart

7.2.3 Process Permeate Pump

The process pump draws permeate through the membrane modules. In FILTRATION, a permeate flow set point (R3) controls the speed of the process pump.

7.2.4 Filtration Tank

The filtration tank is described as the tank containing the membrane modules. During FILTRATION the process pump draws water through the membranes and delivers it to the permeate header and to the backwash membranes or discharge.

7.2.5 Filtration Tank Isolation Gate

Filtration tank isolation gate is used to isolate the membrane tank from the influent flow during RECOVERY CLEANING S. The OSC will provide the details on gate positions.

7.2.6 Standby Filtration Tank

Several triggers may cause a tank to go to STANDBY rather than going to SHUTDOWN. These triggers include a low membrane tank level (R20), low plant flow demand, or a loss of compressed air. If a low membrane tank level occurs, the tank will immediately proceed to STANDBY. If the STANDBY triggers no longer exist and a start trigger is active, the tank proceeds into FILTRATION. A detailed list of all triggers is provided in chapter 7.5.

7.2.7 Drain Pump and Excess Sludge Removal

The drain pump does not run during FILTRATION and BACKWASH and it is used to drain the membrane tank to the sludge holding tank during DRAIN.

Excess sludge needs to be removed to control the Mixed Liquor Suspended Solids (MLSS, also termed sludge) inside the tank. The standard solution is to discharge the MLSS in certain intervals (R29 & R30). The operator should analyze the sludge to ensure the required mixed liquor concentration in the tank.

7.2.8 Aeration

The membranes are aerated using continuous aeration in VENTING, FILTRATION, BACKWASH and RELAXATION and intermittent aeration in STANDBY. The membrane tank is not aerated while it is being drained.

7.2.8.1 Membrane Aeration Control

The blower supplies low pressure air into the air header. This air header then delivers air into the diffusers. For further details on blower operation, refer to the OSC. There might be more than one blower for multi-train system. The PLC determines the number of blowers required to run and the flow setpoint for these blowers.

Membrane trains are aerated in FILTRATION, BACKWASH, RELAXATION, intermittently in STANDBY and some steps of MAINTENANCE CLEAN, RECOVERY CLEAN and NEUTRALIZATION. The blower operates at a constant speed. The PLC starts, stops or adjusts the speed of the membrane blower as necessary based on the aeration demand which is set in the HMI (R10).

If an aeration isolation valve is required to close and fails to close, aeration continues and the train does not proceed to Standby due to an active Standby Trigger. An alarm is triggered. If the aeration isolation valve fails to open, the train goes to the fault step to prevent membrane fouling due to insufficient aeration.

7.2.8.2 STANDBY Aeration

In STANDBY, the tank is aerated at its lowest acceptable air flow rate intermittently. The blower starts to aerate for a couple of minutes (R27 Run time for Interval crossflow aeration standby) to provide mixing and then stops for a certain interval (R26 Interval between crossflow aeration standby).

7.2.8.3 Blower Low Airflow

A low flow switch is located on the discharge of blower. If the switch is active, an alarm occurs and the PLC shuts down tank until there is sufficient aeration capacity. If all blowers are faulted, all tanks are shut down.

7.2.8.4 Air Compressor Control

Local control panels control the compressors (blower for crossflow aeration). There should be a low-pressure switch on the common discharge piping which is used to alarm and callout. When this alarm is active, tank in any state will switch to STANDBY.

7.2.9 Backwash Equipment Control

The membranes are backwashed using process pump. Treated water is periodically reversed back through the membranes to maintain stable transmembrane pressures.

The PLC controls the pump speed to BACKWASH the membrane module at a set flow rate (R4) up to a maximum TMP (R15). A transmitter on the membrane header is used to calculate the BACKWASH TMP. This provides membrane protection against over-pressurization. If the TMP is too high, the TMP high trigger is active and the flow control PID loop output is captured. This value becomes the maximum value for the output of the flow control PID loop.

When the TMP high trigger becomes active, the PLC gradually reduces the maximum for the flow PID loop output until the TMP high trigger is not active, (i.e. TMP is less positive). When the TMP high trigger becomes inactive, the maximum value is then gradually increased until the TMP high trigger is active again or continues to increase until the maximum value for the flow control PID loop output equals 100 %. This control strategy allows the PLC to vary the pump speed to maximize flow while avoiding excessive TMP across the membranes. The BACKWASH duration, production cycle duration, TMP setpoint and flow setpoint can be set through the HMI.

7.2.9.1 Backwash Sequencing

The filtration tank is given a fixed scheduled time in the master production cycle timer to begin either a BACKWASH or RELAXATION or a combination. The tank is always backwashed at the same time slot of the master FILTRATION cycle timer. But this time can be adjusted as needed (R5 to R8). In addition, there is an option to do a BACKWASH in a interval for every few cycles, setting this interval at 1, BACKWASH will be carried out each cycle.

The master production cycle timer starts when there is no FILTRATION and it starts once is requested to start FILTRATION. The timer restarts every time it times out. The operator can initiate a BACKWASH from the HMI by pressing the BACKWASH button. This button is disabled if the tank is in BAKCWASH.

7.2.10 Relaxation

RELAXATION control is an alternative to backwashing. If a BACKWASH failure occurs and no pump is available, the PLC will place the tanks into RELAXATION mode.

In RELAXATION mode, the PLC will stop permeating and the membranes sits for an operator entered duration before continuing FILTRATION. During this time solids that have concentrated around the membrane will be distributed away from the membrane surface by the aeration.

7.2.11 Turbidity Measurement

An accurate and simple way to determine the separation performance of the system is to monitor the turbidity in the effluent. High turbidity in the effluent indicates that there are leaks, and the system should be stopped immediately and the source of the failure should be investigated. A turbidity measurement is not mandatory to ensure a stable process.

7.2.12 Recirculation Control

7.2.12.1 Recirculation Flow Control

The recirculation/drain pumps circulate RAS at an operator adjustable ratio based on the required plant flow demand and to keep the MLSS within the required range. As the plant flow demand increases the recirculation flow demand increases, causing the recirculation/drain pump(s) to speed up. The PLC performs these calculations.

7.2.12.2 Recirculation/Drain Pumps

Filtration tank has a dedicated recirculation/drain pump. Recirculation/drain pumps will operate during all modes of operation excluding MAINTENANCE CLEANING and NEUTRALIZATION. In RECOVERY CLEANING, the recirculation/drain pump drains the membrane tank. In DRAIN, the recirculation/drain pump drains the membrane tank.

7.2.12.3 Standby Recirculation

When tank in STANDBY is aerated, the recirculation/drain pump will operate for the Standby aeration duration.

7.2.13 Temperature and pH Measurement

The temperature affects various system parameters and must be continuously monitored. The temperature affects viscosity which in turn has an effect on the sludge filterability. An accurate temperature is imperative when setting flux levels and calculating costs associated with energy use.

It is important to be able to measure the pH in the MBR tank as well as the pH in the pipes during chemical cleanings. To monitor both, the sensor should be installed between the membranes and the dosing point of the chemicals. In this case, the permeate quality represents the pH in the MBR tank.

7.2.14 Venting

A venting tank is installed at the highest point of piping and venting is conducted automatically after a certain amount of production cycles which can be entered in the HMI. This process is detailed in the OSC.

After a certain number of filtration cycles (R22), an automatic venting (also termed de-aeration or degassing) of the permeate piping system is conducted. The permeate pump is running in reverse mode (BACKWASH) and filling up the venting tank during this period. The flow can be adjusted in the HMI (R23). This VENTING is mandatory since air is accumulating inside the piping due to crossflow-aeration. If air is not properly removed, TMP calculation and thus permeability may be distorted. There is a pressure limit for VENTING (R24) where the plant goes to STANDBY to avoid bursting of equipment.

7.2.15 MICRODYN BIO-CEL®-MCP MBR

The Mechanical Cleaning Process (MCP) is used for enhanced mechanical cleaning and reducing the chemical consumption. Please read the MICRODYN BIO-CEL® Design Guideline for more information regarding design of MCP plants.

A schematic representation of the MCP process is illustrated in **Figure 3** whereas the MCP beads are illustrated as red dots and the air as blue dots.

The MCP process design and operation is more complex and providing several challenges:

- The MCP must be retained inside the filtration tank and the proper function of the MCP screen needs to be monitored closely to avoid overflow of filtration tank or an increased MLSS concentration.
- The operation is stopped and operation goes to SHUTDOWN with recirculation pump OFF as soon as the alarm level is obtained in one of the following conditions:
  - The pressure difference between both sides of the MCP screen is exceeded and damage of screen is possible.
  - Max. level in filtration tank is exceeded due to blocked screen.
  - Max. MLSS exceeded due to blocked screen.

In case an emergency occurs the MCP screen needs to be cleaned either by aeration or mechanically.

7.3 Monitoring Parameter

7.3.1 Monitoring Parameter Membrane

The main operation modes are the FILRTRATION, BACKWASH, RELAXATION and VENTING. The sequence of these steps is termed production cycle. The TMP and Flow curve is illustrated in **Figure 13.** TMP and flow during automatic operation mode.

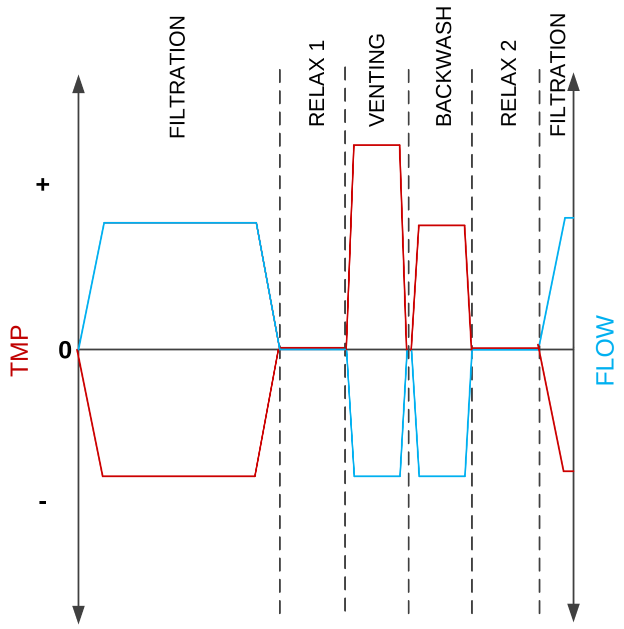

Figure 13. TMP and flow during automatic operation mode

7.3.1.1 Trans-Membrane Pressure (TMP) Calculation

TMP is calculated by using the equation below. During FILTRATION the value is negative, for BACKWASH and CIP, it is positive. A schemtic representation of TMP factors is in **Figure 14**.

$$TMP \; = \; P_P \; (Header \; Pressure) - P_S \; (hydrostatic \; pressure)$$

Where:

- Pp is the pressure measured by pressure transmitter in the permeate header

- Ps is the hydrostatic pressure due to corresponding water height above the pressure transmitter. This value is considered a positive number when pressure transmitter is below the water level and a negative number when it is above the water level.

For TMP calculation the varying water level needs to be taken into account and therefore the hydrostatic pressure PS is calculated based on the following equation.

$$P_S = P_L\ (liquid\ level) - dp\ (correction\ factor\ between\ pressure\ gauge\ and\ bottom)$$

Where:

- P_L is the pressure at the liquid level
- d_P is the correction factor between the pressure gauge and the bottom of the tank.

In FILTRATION, an increased TMP value means a larger pressure differential because the pressure inside the membranes is lower than outside the membranes. This corresponds to a lower number as expressed in engineering units. Therefore, a high FILTRATION TMP is actually expressed as a Pressure Differential Alarm Low.

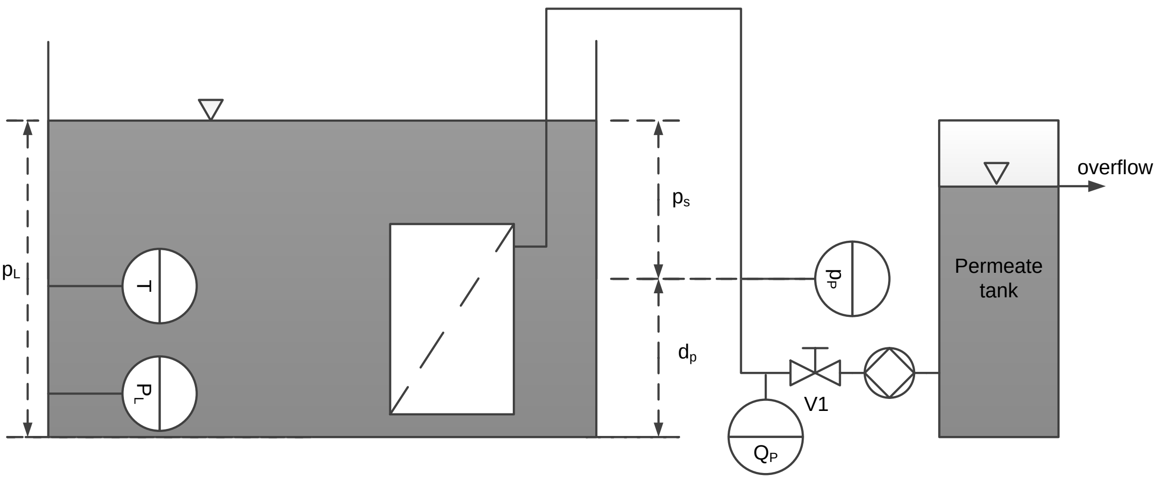

Figure 14. TMP calculation

When a pressure loss higher than 10 mbar (0.15 psi) is expected due to piping, this pressure loss needs to be determined and implemented in the PLC.

The PLC continuously calculates the TMP value while in FILTRATION. If the TMP is too low (i.e. too negative) the TMP low trigger is active and the flow control PID loop output is captured. This value becomes the maximum value for the flow control PID loop output.

When the TMP low trigger becomes active, the PLC gradually reduces the maximum for the flow PID loop output until the TMP low trigger is not active, (i.e., TMP is less negative). At the moment when the TMP low trigger becomes inactive, the maximum value is then gradually increased until the TMP low trigger is active again, or continues to increase until the maximum value for the flow control PID loop output equals 100 %. This control strategy allows the PLC to vary the pump speed to maximize flow while avoiding excessive TMP across the membranes.

7.3.1.2 Flow and Flux

The permeate flow rate is positive during FILTRATION and negative during BACKWASH and is transferred to PLC with the respective signs plus and minus. Make sure that the flow device can measure in both directions.

The flux is the area-specific flow through the membrane surface area and needs to be calculated for monitoring of permeability:

$$Flux\ [LMH] = \frac{Flow\ rate\ [\frac{L}{h}]}{Membrane\ area\ [m^2]}\ or\ \text{Flux [gfd]} = \frac{\text{Flow rate } \left[\frac{\text{gal}}{\text{min}}\right]}{\text{Membrane area [ft}^2\text{]}}$$

7.3.1.3 Temperature Corrected Permeability

The temperature corrected permeability is taking temperature compensation into account and is calculated based on the Flux and TMP. This monitoring parameter is added to the HMI for monitoring of the process. For calculation please take a positive value for TMP.

$$Temperature\ corrected\ permeability\ \left[\frac{LMH}{bar}\right] = \frac{Flux\ [LMH]}{TMP\ [bar]} \cdot 1.024^{(20-temperature\ in\ °C)}\ or$$

$$Temperature\ corrected\ permeability\ \left[\frac{gfd}{psi}\right] = \frac{Flux\ [gfd]}{TMP\ [psi]} \cdot 1.024^{(20-temperature\ in\ °C)}$$

7.3.2 Monitoring Parameter Diffuser

The diffuser system needs to be monitored and therefore it is recommended to track the pressure loss of the diffuser, temperature and air flow.

For proper monitoring of the pressure loss, the liquid level inside the filtration tank needs to be substracted. Please find details regaring the depth of standard tanks in the MICRODYN BIO-CEL® Design Guideline.

The temperature and flow rate are additionally monitored for the blower.

7.4 Chemical Cleaning

7.4.1 Clean in Place (CIP) Controls

The membranes require cleaning to maintain peak performance. There are two types of cleaning methods; MAINTENANCE CLEANINGS and RECOVERY CLEANINGS. The cleaning chemical is either citric acid or sodium hypochlorite for MAINTENANCE CLEANINGS and RECOVERY CLEANINGS.

RECOVERY CLEANINGS are operator initiated from OFF and should have the operator present during the majority of this clean. MAINTENANCE CLEANING is scheduled through HMI and is automatically initiated by PLC based on preset schedule.

Sodium Hypochlorite Cleaning Equipment

Sodium hypochlorite is used to remove organic contaminants from the membranes. The sodium hypochlorite pumps are often air diaphragm pumps. The PLC requests a sodium hypochlorite valve which needs to be defined (referred in the following as TBD) for MAINTENANCE CLEANINGS or valve (TBD) for RECOVERY CLEANINGS to open to run the pump in specific steps during the cleaning procedure. Consult the OSC for these steps.

Citric Acid Cleaning Equipment

Citric acid is periodically used to remove inorganic contaminants from the membranes such as calcium carbonate, manganese and iron compounds. The citric acid pumps are often air diaphragm pumps. The PLC requests a citric acid valve (TBD) for MAINTENANCE CLEANINGS or valve (TBD) for RECOVERY CLEANING to open to run the pump in specific steps during the cleaning procedure. Consult the OSC for these steps.

7.4.2 Maintenance Cleaning

MAINTENANCE CLEANINGS are scheduled through the HMI and are automatically initiated by the PLC based on a 24 hour clock. The operator is able to schedule one MAINTENANCE CLEANING per day. Operator enters the starting time and selects the cleaning chemical for the clean.

When it is time to perform a MAINTENANCE CLEANING, the PLC compares the current plant flow demand with the available capacity if one tank is not in service. If the plant permeate flow demand exceeds this capacity, then scheduled MAINTENANCE CLEANING is skipped or aborted, an alarm occurs to inform the operator.

If the plant permeate flow demand does not exceed the available capacity, the MAINTENANCE CLEANING starts after the tank has completed its production cycle. If a tank is in STANDBY, it directly goes to MAINTENANCE CLEANING.

7.4.2.1 Maintenance Cleaning Sequence

This cleaning can be done in biomass/process fluid. The standard MAINTENANCE CLEANING is 60 minutes long. The MAINTENANCE CLEANING procedure is summarized below:

Table 17. Standard Maintenance Cleaning Procedure

Steps	Procedure
1	Stop filtration of membrane train scheduled to be cleaned Continue to aerate membranes and re-circulate mixed liquor for 10 minutes (R33)
2	Shut off mixed liquor re-circulation and isolate membrane tank Shut off membrane aeration system
3	BACKWASH membranes in the train for XXX seconds as set in R39 Initial chemical dosing time while dosing appropriate chemical (sodium hypochlorite or citric acid)
4	BACKWASH membranes in the train for XXX seconds (R40 Repeat dosing time) while dosing appropriate chemical (sodium hypochlorite or citric acid)
5	Relax membranes for total of XXX seconds (R41 Repeat soaking time)
6	Repeat steps 4 and 5 for total of 7 BACKWASH and RELAXATION cycles (R42)
7	BACKWASH membranes in the train for XXX seconds (R47, or longer if needed for larger systems) without adding chemicals to flush out the chemicals from piping (R47)
8	Open the valves that isolate the membrane tank/train
9	Turn on mixed liquor re-circulation pump and membrane aeration for 5 minutes (R48)
10	Resume normal operation

7.4.2.2 Calculation of Chemical Concentrations

The flow of chemical pumps can be calculated according to the following equation based on the target chemical concentration divided by the source chemical concentration multiplied by the permeate flow.

Please take into account that sodium hypochlorite is degraded very fast appr. 1 g/l/d at 20 °C for a new batch with 150 g/l. Therefore, the source and target chemical concentration should be changeable in the HMI (R35 to R38).

$$Chemical\ flow = Permeate\ flow \cdot \frac{Target\ chemical\ concentration}{Source\ chemical\ concentration}$$

7.4.3 Recovery Cleaning

RECOVERY CLEANING can only be carried out if it is in RECOVERY CLEANING mode. The cleaning chemical is either citric acid or sodium hypochlorite. The operator turns the tank OFF and then selects either the Recovery Clean with Citric Acid button or Recovery Clean with Sodium Hypochlorite button for the cleaning to begin.

During a RECOVERY CLEANING there are several prompts which the operator must address. Consult the OSC for further details. As a result, it is suggested to have the operator present during the RECOVERY CLEANING so that these prompts can be responded to in a timely manner.

The steps of cleaning are in line with the MAINTENANCE CLEANING and the parameters can be adopted for the RECOVERY CLEANING. Otherwise an additional parameter set can be programmed in the PLC as can be found in Table 22 (R33 to R48).

The steps for RECOVERY CLEANING are:

Table 18. Recovery Cleaning Procedure

Steps	Procedure
1	Stop filtration of membrane train scheduled to be cleaned Continue to aerate membranes and re-circulate mixed liquor for 60 minutes
2	Shut off mixed liquor re-circulation and isolate membrane tank Shut off membrane aeration system
3	Drain the membrane tank manually or using the re-circulation pump
4	Fill the membrane tank with permeate water using an external pump. Note that other membrane trains are required to stay in operation mode in order to keep the permeate tank full of permeate during this process
5	Aerate membranes for 60 minutes
6	Drain the membrane tank again to remove all excess sludge removed from membranes
7	Fill up the membrane tank with permeate to 80 % of the cleaning level
8	BACKWASH membranes in the train for 600 seconds while dosing appropriate chemical (2,000 mg/L sodium hypochlorite or 2,000-5,000 mg/L citric acid)
9	BACKWASH membranes in the train for 20 seconds while dosing appropriate chemical (2,000 mg/L sodium hypochlorite or 2,000-5,000 mg/L citric acid)
10	Relax membranes for total of 120 seconds
11	Repeat steps 9 and 10 until membrane tank liquid level is 100 % of the cleaning level
12	Soak membranes in the cleaning solution (2,000 mg/L sodium hypochlorite or 2,000-5,000 mg/L citric acid for 5-12 hours
13	Continue to BACKWASH membranes without adding chemicals until the membrane tank liquid level is at the cleaning level
14	Open the valves that isolate the membrane tank/train
15	Turn on mixed liquor re-circulation pump and re-circulate mixed liquor for 15 minutes
16	Turn on membrane aeration and continue to re-circulate mixed liquor for additional 15 minutes

Steps	Procedure
17	Resume normal operation

The cleaning level is the level where the cleaning needs to stop to avoid overflow of filtration tank and is considered to use the maximum level available in the filtration tank.

7.4.4 Neutralization

The goal of NEUTRALIZATION is to remove residual chlorine. Recirculation from filtation tank to biology is stopped. If several repetitions of aeration and soaking time are not sufficient, please refer to the MICRODYN BIO-CEL® O&M Manual for additional information of NEUTRALIZATION options.

The operator selects the Neutralization button to proceed to NEUTRALIZATION mode. The Neutralization button is available in OFF and in the last step of RECOVERY CLEANING.

The steps for NEUTRALIZATION are:

Table 19. Neutralization procedure

Steps	Procedure
1	Fill the filtration tank to defined level from the membrane distribution channel.
2	Aerates the membrane tank.
3	Soaking time period for a defined duration and then either proceed to next step if the clean was with sodium hypochlorite or proceed to step 5 if the clean was with citric acid.
4	The operator manually checks the residual chlorine concentration. The operator selects the Confirm Neutralization button to proceed to next step when the residual chlorine concentration is less than 10 ppm. The operator selects the Resume Neutralization button when the residual chlorine concentration is greater than 10 ppm. The PLC will proceed to step.
5	BACKWASH without chemical.
6	Proceed to OFF.

Consult the OSC for specific details on the steps and set points used in this mode.

The NEUTRALIZATION is initiated by the operator after the extended chemical soak step in RECOVERY CLEANING. The operator is then responsible for confirming the NEUTRALIZATION if the clean was with sodium hypochlorite.

7.5 Triggers & Alarms

A trigger is a normal event that can clear an alarm or be one of several points in a sequence of events.

Alarms are used to identify a problem with the system. Depending on the nature of the problem the alarm may either shutdown the tank, place the tank to STANDBY, and initiate a callout to notify the operator that there is a problem. It is understood that the operator will acknowledge the alarm and address the situation. If the problem is not corrected, production quality and quantity will drop off quickly.

An alarm that is activated by an instrument, pressure transmitter, flow transmitters, or level instrumentation, typically requires a pump or another device to be on to generate the required flow or pressure. Otherwise, the alarm will be ignored if the device to be protected is off.

All alarms are indicated with a message on the screen. The operator cannot reset the alarm without the correct password. All alarms and the time they occurred are recorded on the alarm history screen.

Some alarms can shutdown the tank. These alarms close appropriate valves and stop the pumps. The shutdown alarm puts the tank to SHUTDOWN mode. Restarting after a shutdown will require the alarm to be reset. Devices which are being controlled remotely cannot have their status changed by the PLC. Typical alarms that SHUTDOWN a tank and alarms that put the tank to STANDBY are listed in**Table 20**.

Please note that just the most important membrane-related errors are described below and it is in the responsibility of the system integrator to properly implement all required errors for safe operation of the entire system.

Standard operational parameters which are used in the PLC and can be altered in HMI are given in Table 22.

Table 20. Tank alarms with warning, shut-down, standby

Error no. and description (possible cause)		SHUT DOWN	STANDBY
1.	Power failure or inproper shut-down (manual shut-down during FILTRATION)	X	
2.	Overflow biology tank (level sensor broken)	X	
3.	Overflow filtration tank (level sensor broken)	X	
4.	R16 Minimum level biology (no inflow)		X
5.	R20 Minimum level filtration tank (recirculation pump down)	X	
6.	Minimum level permeate tank (no FILTRATION of other tanks during cleaning of other tank)	X	
7.	R14 Min. FILTRATION pressure (negative value) undershot (membrane fouled/ scaled)	X	
	R15 Max. BACKWASH pressure exceeded during production cycle (membrane fouled/ scaled)		X
8.	R15 Max. BACKWASH pressure exceeded during chemical cleaning (membrane fouled/ scaled)	X	
9.	R24 Pressure limit for venting exceeded		X
10.	R32 Decreased permeability value undershoot and cleaning required		X
11.	P04 on and both valves Vx1-01 and Vx4-01 are closed (valves broken and protection of bursting)	X	
12.	Error voltage (Malfuntion in energy supply)	X	
13.	Motor protection P04 permeate pump (pump damaged)	X	
14.	Frequency inverter (F) P04 with malfunction, max. temperature exceeded (no proper cooling of FI)	X	
15.	Motor protection P05 recirculation pump (pump damaged)	X	
16.	Error analog signal flow meter FIC 01-001 (air in piping)		X

Error no. and description (possible cause)	SHUT DOWN	STANDBY
17. Error analog signal flow meter FICR 04-004 (air in piping)		X
18. PLC Error (Tripped breaker inside panel)		X
19. Archieving not functioning (storage full)		
20. Low flow blower G02 (blower damaged)	X	
21. R11 Max. pressure for G02 achieved (diffuser plugged, sludge inside diffuser/ piping)	X	
22. R28 Max. MLSS in filter tank (QIC 04-003) exceeded (too low sludge discharge or low recirculation flow)		X
23. Compressed Air-Low pressure valves RECOVERY CLEANING (Insufficient Compressed Air Supply to operate pneumatically actuated valves)	X	
24. Compressed Air-Low pressure valves FILTRATION, BACKWASH, RELAXATION, MAINTENANCE CLEANING (Insufficient Compressed Air Supply to operate pneumatically actuated valves)		X
25. Just for MICRODYN BIO-CEL®-MCP process: R49 Pressure difference MCP screen exceeded	X	

7.5.1 Plant Operating Interface

To accommodate the above operational requirements and all other control, display, and monitoring requirements, the plant needs a HMI for access to plant controls. The HMI communicates with the Programmable Logic Controller (PLC), which in turn controls the plant.

7.5.2 Password Access & Privileges

The entire plant is controlled from the PLC through a HMI. The ability to silence the horn and acknowledge alarms does not require a password, but alarms cannot be reset. To gain access to make changes on the HMI, the operator is required to enter the correct password.

A screensaver blanks the screen after a set amount of time of inactivity. The screen is reactivated by a single touch. Reactivation cannot select a device or operating mode.

In order to access the control screens, the individual must enter a correct password then press Enter. There are two levels of password protection; Operator and Supervisor. The operator password is factory set; consult the CLSC for the operator password.

The supervisor password can be modified from the HMI. There is no limit to the number of times another password can be attempted. The password must be re-entered after a set amount of time of inactivity.

7.5.3 Screen Color-Coding

The color-coded status indicates whether the device is either running automatically, shutdown, in STANDBY, OFF. Manually overridden, etc.

The HMI uses the color-coding shown below.

Table 21. HMI Color Code Devices Charts

Color	Valve	Pump
Green	OPEN	ON
Yellow	CLOSED	OFF
Blue	STANDBY	STANDBY
Red	SHUTDOWN, OFF	SHUTDOWN, OFF

Power Interruption / Power Up

When a loss of power occurs, the tank will immediately proceed to POWER OFF mode. After power returns, the plant powers up common equipment and then the tank will start-up automatically.

Loss of Communication Alarms

During operation of the MICRODYN BIO-CEL® system, there are 'heartbeat' signals generated by each PLC. Each 'heartbeat' signal is a counter that increases by one unit each second. When the communication with a PLC is lost, the PLC that is monitoring the "heartbeat" counter detects that the value of the counter has not changed for a preset time, e.g. few seconds, and alarms. When the counter reaches for example 20,000 it restarts counting from zero.

7.5.4 Loss of Communication Alarm with Plant SCADA

When there is a loss of communication with the plant SCADA, the tank proceeds to SHUTDOWN.

7.5.5 Signals for Communication

For the BIO-CEL membrane system to maintain optimal performance, information must be communicated between the plant SCADA and the PLC.

Operating parameters of the BIO-CEL system such as flowrates, pressures, tank modes, etc. are available for communication, if necessary, when the plant SCADA is required to only monitor these parameters. The MBR system operates in a continuous automatic mode controlled by PLC, which shall interface with the plant SCADA system.

7.5.6 Plant PLC to the MBR Module PLC Signals

The list given below shows the signals that are communicated from the plant SCADA over the network to the MBR module PLC to operate the membrane system.

1. Feed Flowrate
2. Permissive to run the tank
3. Running signal for blower
4. Running signal for process pump
5. Running signal for recirculation drain pump

7.6 Standard Operational Parameters

The standard operational parameters are implemented in PLC and can be altered in HMI according to the recommended range detailed in the table below.

Table 22. Standard Operational Parameters

Parameter	Basic setting	Range
R1 Membrane area	Project design (m^2, ft^2)	0..99999
R2 Correction factor TMP_{dp}	Project design (mbar, psi)	-999..999
R3 FILTRATION flow	Project design (m^3/h, gpm)	0..999
R4 BACKWASH flow	10-15 l/m^2/h/bar (6-8.9 gfd)	0..999
R5 FILTRATION time	510 sec	0..999
R6 RELAXATION time 1	30 sec	0..99
R7 BACKWASH time	30 sec	0..99
R8 RELAXATION time 2	30 sec	0..99
R9 BACKWASH interval	1	0..999
R10 Crossflow air flow	Project design (Nm^3/h; SCFM)	0..9999
R11 Max. pressure air flow line	Project design	0..999
R12 Recirculation flow	Project design	0..999
R13 Min level Permeate tank	Project design	0..999
R14 Min. FILTRATION pressure (negative value)	-400 mbar (-5.8 psi)	0..-400
R15 Max. BACKWASH pressure	+150 mbar (+2.2 psi)	0..150
R16 Min. level biology	Project design	0..999
R17 Medium level biology	Project design	0..999
R18 Peak level biology	Project design	0..999
R19 Max. level biology	Project design	0..999
R20 Min. level in filtration tank	Project design	0..999
R21 Max. level in filtration tank	Project design	0..999
R22 Interval between VENTING	2 to 5	0..99
R23 BACKWASH flow for VENTING	Project design	0..999
R24 Pressure limit for VENTING	Project design	0..999
R25 Time of VENTING	30 sec	0..99
R26 Interval between crossflow aeration standby	25 min	0..99
R27 Run time for Interval crossflow aeration standby	5 min	0..99
R28 Max. MLSS in filter tank	15 g/l	0..999
R29 Interval surplus sludge pump on	Project design	0..999
R30 Interval surplus sludge pump off	Project design	0..999
R31 Duration of decreased permeability range	10 days	0..99

R32	Decreased permeability value	130 LMH/bar (5.2 GFD/psi)	0..9999
R33	Time Crossflow aeration before MAINTENANCE CLEANINGS	10 min	0..99
R34	Timer between two MAINTENANCE CLEANINGS	14 d	0..99
R35	Source chemical concentration bleach	150 g/l	0..999
R36	Target chemical concentration bleach	250 mg/l	0..2000
R37	Source chemical concentration citric acid	450 g/l	0..999
R38	Target chemical concentration citric acid	2000 mg/l	0..10000
R39	Initial chemical dosing time	540 sec	0..9999
R40	Repeat dosing time	40 sec	0..99
R41	Repeat soaking time	280 sec	0..99
R42	number of re-pulses R40 Repeat dosing time	7	0..99
R43	BACKWASH flow permeate pump MAINTENANCE CLEANING	Project design	0..999
R44	BACKWASH flow chemical dosing pump alcalinic cleaner	Project design	0..999
R45	BACKWASH flow chemical dosing pump acid cleaner	Project design	0..999
R46	BACKWASH flow without chemicals	Project design	0..999
R47	Time BACKWASH without chemicals	300 sec	0..99
R48	Time Crossflow aeration after MAINTENANCE CLEANING	15 min	0..99
R49	Pressure difference MCP screen exceeded	Project design	0..999

7.7 Data Recording

The following data must be recorded by the system automatically or should be logged by the operators manually in a digital logbook. The online data needs to be archieved by PLC and provided to MN preferably analysed in a report form. The minimum requirement is a CSV data format to analyze data afterwards.

In general, it is recommended to implement the following online measured parameter into the general overview page of the PLC.

It is recommended to add the option that laboratory measurements can be added to the PLC and saved together with online data.

Table 23. Logged data for process monitoring

System Component	Parameter	Frequency of Measurement Online	Laboratory
Inflow	pH	-	3/week
	COD in mg/l	-	3/week
	BOD_5 in mg/l	-	1/week
	Total Suspended Solids in g/l (TSS)	-	3/week
Mixed liquor (sampling in filtration tanks)	Mixed Liquor Suspended Solids in g/l (MLSS)	Hourly*	3/week
	Mixed Liquor Volatile Suspended Solids in mg/l (MLVSS)	-	1/week
	Filterability (e.g. TTF or CST) Sedimentation properties (ISV)	-	1/week
	Fat, oil, grease in mg/l (FOG)	-	1/week
	pH	Hourly	3/week
	Temperature in °C or °F	Hourly	
MBR Modules	Level filtration tank in m or ft	Hourly	
	Transmembrane Pressure in mbar or psi (TMP)	Hourly	-
	Transmembrane Pressure during backwash in mbar or psi	Hourly	
	Flow rate per line in m³/h or gpm	Hourly	-
	Flux in L/m²/h/bar or gfd		
	Temperature in °C or °F (effluent or mixed liquor)	Hourly	-
	Normalized permeability (temperature corrected) in L/m²/h/bar or GFD/psi	Hourly	-
	Temperature corrected permeability based on TMP_{mid} in L/m²/h/bar or GFD/psi	Hourly	-
	Cross-flow air scour rate per line in Nm³/h or SCFM	Hourly	-
	Air pressure in mbar or psi in air header corrected by level	Hourly*	3/week
	Air temperature in air header in °C or °F	Hourly*	3/week
Chemical Cleaning	Concentration in mg/l and pH of cleaning solution	Note date and required data for each chemical cleaning	
	Chemical fill volume in m³ or gal (amount of chemical solution per line)		
	Soaking time from start backwash till end of soaking in hours		
	Consumption of source chemicals in L or gal		
Effluent	Total Suspended Solids in mg/L	-	1/week
	Turbidity in NTU orFNU	Hourly*	3/week
	COD in mg/l	-	3/week
	pH	Hourly	3/week

*Recommended alternative measurement data and frequency; all others (without *) are required data for warranty purposes.

8 Auxillary Equipment

In addition to the instrumentation mentioned previously in chapter 7, other auxiliary equipment may be needed to monitor the system appropriately. Instruments measuring dissolved oxygen, MLSS and tank levels are recommended to ensure the system is operating at optimal conditions. A complete list of suggested auxiliary equipment may be found in Appendix: Device List.

8.1 Cross-Flow Blowers

Another important aspect of a system using MICRODYN BIO-CEL ® MBR modules is the supply of air. The air cross-flow creates turbulence on the membrane surface to curb short term fouling while continuously supplying oxygen to the sludge to maintain healthy biological conditions.

Aeration information for all modules is listed in **Table 10**.

Generally, one blower is needed per filtration line, but it is suggested that either reserve blowers are stored in case of failure or the system is designed with redundancy so that adequate air can be supplied at all times. Additionally, pressure losses associated with piping, water level differences and pressure loss from the diffusers should be considered when designing the aeration system.

8.2 Permeate Pump

Once the permeate is physically separated from the sludge in the filtration tank, the permeate collection system transfers the clean water from the filtration tank to a permeate storage tank.

Ideally, the permeate pumps are reversible in their flow direction and have a pressure range of -500 to +500 mbar (-7.25 to +7.25psi) (e.g. an eccentric screw pump or a rotary piston pump). It is important that the pump has the described qualities to ensure that the pump can both extract permeate from the sludge during filtration (through the permeate channel) and conduct the reverse module backwashing.

Each individual filtration line should be assigned to a separate permeate pump. The pump is sized based on the maximum gross flux and the membrane area (see chapter 4.1). Additionally, it is suggested that the pumping system is designed, in coordination with piping and valve schemes, with redundancy so that multiple pumps have the capability to provide adequate power to multiple lines, or that spare pumps are stored on site to ensure minimal downtime in the event of unexpected failure. Troubleshooting may be simplified if the plumbing system allows for the isolation of single trains and modules.

The preferred operation of the BIO-CEL MBR modules includes permeate pumps and backwashing, however operation via gravity flow (e.g. without permeate pumps) in combination with or without backwashing is also possible. Please consult your MICRODYN-NADIR sales representative if you consider operating your BIO-CEL system with gravity flow.

8.3 Permeate Pipes & Valves

A series of pipes, valves and fittings connect the permeate pump (and the permeate tank) to the modules. A clever plumbing system configuration is imperative to ensure that the entire MBR system operates properly while maintaining the flexibility and redundancy mentioned earlier in chapter 8.2. A short permeate piping system also helps minimize the overall pressure drop.

Small amounts of air are carried through the pipes along with the permeate as a result of the slight vacuum needed to facilitate filtration. The captured air will accumulate at high points along the piping system and form air pockets which will interfere with the pressure measurement in the system. To counteract formation of air pockets, the piping system should only have one high point with a venting tank mounted in this position (see chapter 8.5). Additionally, the pipes should be sized so that the permeate velocity is below 1 m/s (3.3 ft/s) (V_p << 1 m/s) throughout the system.

The venting tank is not needed if the only high point of the piping system is the permeate tank at the end of the permeate extraction system. All air will be exhausted in the permeate tank and does not cause any misreading of the TMP sensor.

8.4 Permeate Tank

Another important component of the permeate collection system is the permeate tank. Once the clean water is separated from the sludge by the membranes the permeate pump transfers permeate through the piping system to the permeate tank. It is important that the tank is sized so that it contains enough clean water for a chemical backwash at any time. If the system is configured with multiple filtration lines, the volume of the permeate tank may be smaller. This is because as one permeate line is cleaned, the other lines will continue to supply permeate. It is very important to cover the permeate tank and to disinfect it regularly to avoid the formation of a biofilm. Please also avoid direct sunlight since both issues lead to an algae growth in the tank. Please contact MICRODYN-NADIR to discuss the right size of your permeate tank.

The tank should be operated in overflow mode so that once an adequate amount of permeate is stored for backwashing, the excess is discharged or reused.

Table 24. Permeate Tank Volume

Permeate Tank Volume	Single Train Plants	Multiple Train Plants
Minimum Volume	3 liters for every m^2 membrane surface (0.07 gal/ft^2)	Volume for one intensive cleaning minus Volume of the produced permeate of other trains
Maximum Volume	5 liters for every m^2 membrane surface (0.12 gal/ft^2)	Volume for one intensive cleaning

8.5 Venting System

As mentioned in chapter 8.2, the vacuum needed to extract permeate through the membranes also introduces air into the permeate pipes which must be expelled. To counteract the tendency for air accumulation, the piping system should only have one high point, and a venting tank should be located at this point. To ensure that the tank is at the highest point, there should be an incline in the piping between the venting tank and the membranes and a decline in the piping from the venting tank to the permeate tank (at a minimum the pipes between these points in the system should have no slope at all).

The optimum size of the venting tank depends on a multitude of parameters. Please consult with your MICRODYN-NADIR representative for questions or additional information. In general, the following equation may be used as a rough estimate for the tank size:

$$\frac{A_{\text{membrane}}[m^2]}{50} = \text{Venting Tank Volume [L]}$$

The minimum size of the venting tank should be 10 L (2.6 gal) and the maximum, for economic reasons, should be limited to 100 L (26.4 gal). It is favorable if the tank is transparent or has a window so that the operator can visually monitor the level of gas accumulation and optimize the venting process. However, the algae growth issue, as mentioned in the previous chapter 8.4, should also be considered.

The frequency of the venting process strongly depends on the amount of air accumulated. Attributes such as dissolved oxygen (DO) content and TMP determine the amount and rate of air accumulation. High DO in the activated sludge and high TMP exacerbate air accumulation. Additionally, the size of the venting tank dictates the frequency of venting cycles (e.g. a smaller tank can store less air and must be degassed more frequently). The automatic venting cycles may be coupled with normal backwashing cycles. MICRODYN NADIR recommends a venting cycle every 3-4 cycles.

The diagram below outlines a typical schematic of a venting cycle. For venting, V01 closes after V02 is opened and the permeate pump is put into backwash mode. The air collected in the venting tank will be discharged via V02 from the system. The outgoing pipe can discharge the air/water into the permeate tank (preferred solution) or into the filtration tank.

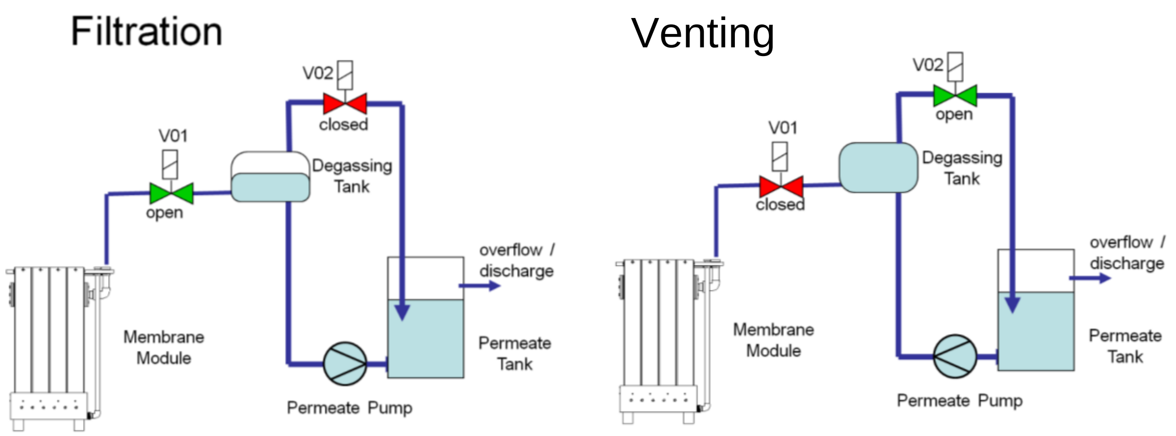

Figure 15. Scheme of venting cycle

9 Appendices

9.1 Appendix: Sieve Test Procedures

Sludge trash in MBR applications is measured and monitored using sieve tests. The sieve test can be used to determine the amount of material that is contained in the mixed liquor of an activated sludge wastewater treatment plant. It can be used to quantify the effectiveness of the pretreatment and screening equipment of the plant.

Materials Required

- Pail or bucket to collect, measure and the mixed liquor volume through the sieve
- Stack of sieves
- Clean wash water (garden hose with spray nozzle)
- Analytical balance (scale)
- Aluminum trays
- Oven (105C)

Procedure

1. Assemble a stack of sieves of the following sizes (largest sieve on top)
   - 2.00 mm (ASTM # 10)
   - 1.00 mm (ASTM # 18)
2. Pour a known volume (60-200 L) of representative mixed liquor through the sieves (see **Figure 17**). Rinse through with clean water periodically if necessary, but take care not to lose any screenings by spraying out of the sieves.

Figure 16. Pouring the mixed liquor through the sieves

3. Shake the sieves gently and wash through with clean water to rinse away the biomass and to clean the collected screenings.
4. Separately collect the screenings from each sieve, and transfer to pre-weighed aluminum trays.
5. Dry the trays of screenings in an oven at 105°C (221°F) for a minimum of 8 hours, or overnight.
6. Weigh the trays again to determine the dry weight of the screenings (**Figure 17** and **Figure 18**).
7. Enter the results into the spreadsheet to calculate the mass concentration of dry screenings in the mixed liquor (mg of dry screenings per L of mixed liquor).

Example of what is collected on the 2-mm sieve:

Figure 17. 2mm sieve residue

Example of what is collected on the 1-mm sieve:

Figure 18. 1mm sieve residue

9.2 Appendix: Abrasion Test & Limits for Use with Immersed Membranes

Introduction

Water and wastewater entering immersed membrane systems may contain different types of particulates of varying sizes and abrasion capacities. Due to sedimentation, the concentration of such particulates will increase in membrane tank. Such material may cause severe damage to the membranes and potentially to the point where the membranes may need to be replaced. The purpose of this chapter is to present a simple test method to analyze feed water to show its abrasiveness characteristics and to recommend limits for use with immersed membranes.

Test Method

Abrasive characteristics are due to a complex relationship between chemical and mechanical actions on a wear block or wear specimen. The Miller Number abrasivity is a relative rate of wear index of the combined effects of both corrosion and mechanical erosion on a 27% Chrome Iron Wear Block (ASTM G075-01). The Gold number abrasivity is a relative rate of wear index of the mechanical erosion on a 24K Gold wear Block. The Gold Number is designed for water with a Miller Number below 20 and is a more accurate continuation in the low abrasivity range of the Miller Number Scale. The Gold number scaled to the Miller Number provides an accurate low abrasivity index.

A standard part of conducting the Miller Number is to conduct a test with erosion-inhibited slurry using Calcium Hydroxide to raise pH to 12 plus to reduce or eliminate erosion. Miller Number abrasivity difference between the regular slurry and the inhibited slurry is the result of corrosion or the synergetic effect of corrosion and mechanical wear. Mechanical wear relates to properties of solids and fluid as well as the solid concentration and load applied to the wear block or wear specimen. Particle mineral composition, hardness, size and shape are the main contributing wear factors for the solid components of the slurry. Hardness of minerals, as measured by Mohs Scale, is identified numerically by standard minerals, from 1 (softest) to 10 (hardest):

1. Talc
2. Gypsum
3. Calcite
4. Fluorite
5. Apatite
6. Orthoclase
7. Quartz
8. Topaz
9. Corundum
10. Diamond

Miller Number abrasivity (rate of wear) correlates with the Mohs Hardness for a particular mineral tested. Rate of wear increases as hardness of the particle tested increases. The size of particles in the slurry has a major effect on the degree of wear, similar to the action of sandpaper. The larger grains on the sandpaper create more wear. Particle shapes ranging from spherical to sharp and angular determine the degree of wear. Beach sand worn to a rounded shape by wave action is much less abrasive than newly fractured quartz of the same general size.

Mechanical wear directly relates to the concentration of the solids at the wear interface and the load that is applied. Increasing the concentration of the solids increases the rate of material loss from the wear block or wear specimen until the wear interface is saturated.

Examples of Different Sources

The following chart summarizes the Gold number for different types of slurry and wastewater and water sources from different plants. The Gold numbers for higher values are scaled from Miller test. In the case of MBR Plant B, the sand found in filtration tank was extremely abrasive and has actually resulted in serious membrane damages.

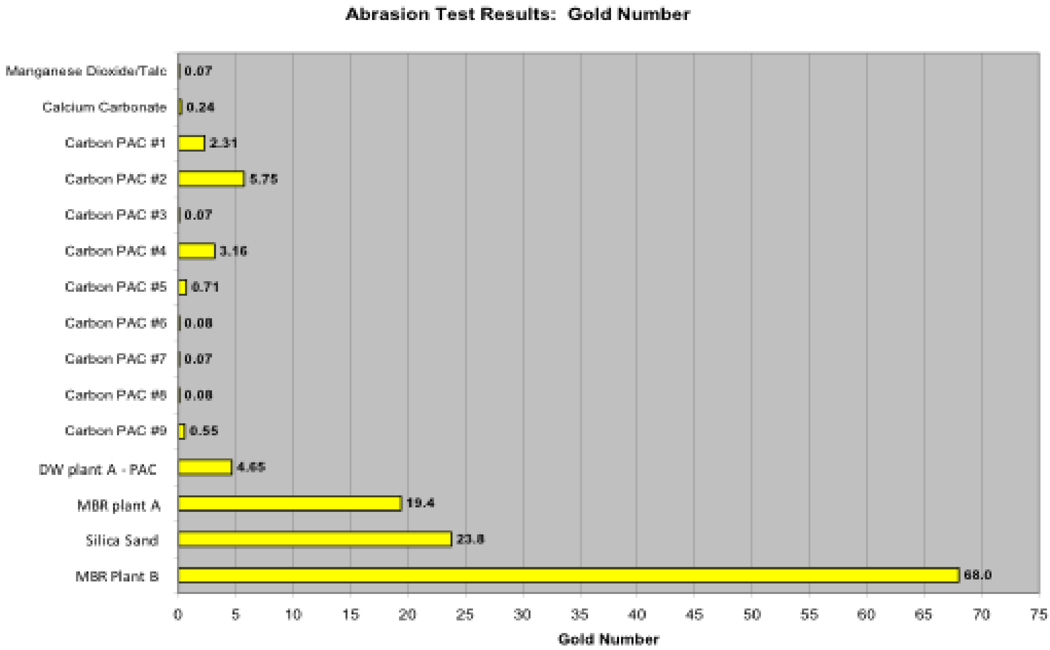

Figure 19. Gold number

The high abrasivity of this sand is due to its silica hardness, large quantity of large particles and sharp and angular material. The following picture shows these particles with a 200 micron photo Dot in the center.

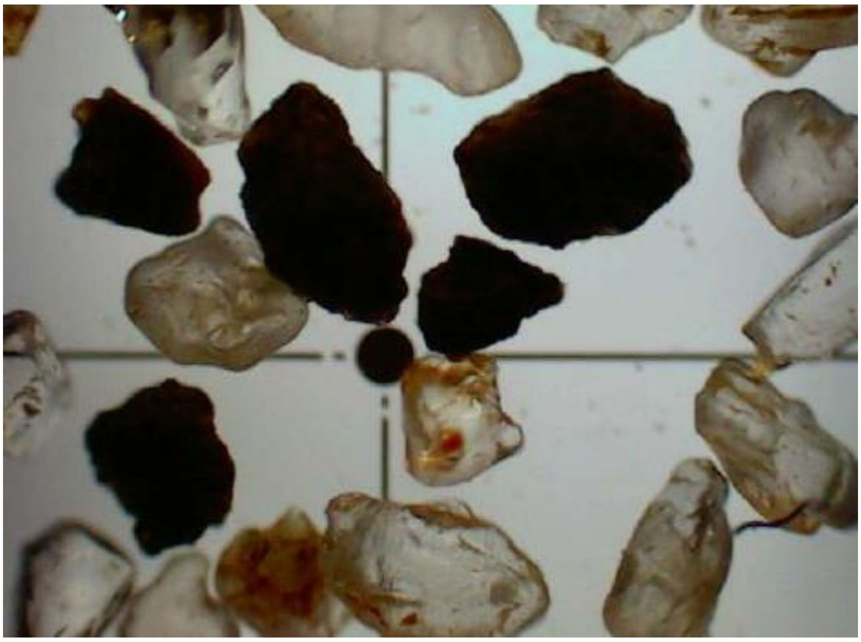

Figure 20. Sand particles

Water Abrasion Limit

Based on previous experiences, it is recommended to ensure wastewater entering the immersed membrane system has a Gold Number less than 30 and preferably less than 20. More abrasive slurries will reduce membrane life and in the case of higher Gold numbers (e.g. gold numbers greater than 50), membranes will be damaged in the matter of a few months depending on aeration rates and frequencies.

If the aeration rate is reduced and is used on an infrequent basis, the membrane life may be improved. The actual life expectancy and risk depends on several factors such as the product itself, aeration process, filtration sequences and tank hydraulics.

9.3 Appendix: Mixed Liquor Sieve Test

A proper pretreatment will ensure very low levels of trash and other harmful material in mixed liquor. The quantity of debris and trash in mixed liquor can be measured by an analytical method known as “Sieve Test”. Routine sieve tests of mixed liquor are used to assess the performance of pretreatment systems. The sieve test should be used initially to commission and test the sludge before exposing the membranes to mixed liquor. It should also be routinely performed routinely to monitor sludge.

For example, if the sieve test results are stable and acceptable after commissioning, but then increase, it is a likely an indication that the pretreatment systems are not working properly. The sieve test procedure is provided in Appendix A.

It is recommended to perform the sieve test during commissioning and before exposing membranes to mixed liquor. After that, the test is used once per month to monitor the quality of sludge. The mixed liquor sample should be taken from the membrane tank. The following guidelines should be used for sludge quality based on the sieve test:

- Material / trash > 2-mm: less than 1 mg/L
- Material / trash > 1-mm: less than 10 mg/L

If the sieve test results are higher than these limits, then it is likely that the fine screens are allowing material to overflow or bypass into the MBR tank and the fine screens and overall pretreatment process should be reviewed for corrective actions. Any overflow or bypass must be eliminated and the performance of the system should be improved to meet these requirements.

9.4 Appendix: Cyclic Valve

Use the following cyclic valve (from Tyco) or similar.:

Butterfly valve, LUG, High performance, 3” or other sizes (e.g. 4”), TYCO, K-LOK, PT#F362-159-K-LOK, ANSI 150#, 316SS LUG STYLE BODY, 316SS DISC, 17-4pH,SS STEM, RTFE SEAT,316SS DU BEARINGS, C/W F79B-006 DA, Double acting pneumatic actuator Morin B Series Scotch Yoke Style, Ductile iron actuator body ad end caps, SS cylinder C?W 2 AVID ZR-112D4N Position monitor C/W with Built-in120VAC SOLENOID energized to close, Power loss opens, rated 120 VAC, NEMA 4, 4,4X

9.5 Appendix: Approved Antifoam Agents

Some of the commercially available antifoam agents that are compatible with MICRODYN BIO-CEL® MBR membrane modules include:

- Nalco IL08
- Nalco, 7465
- Air Products, Surfynol DF-110L
- Air Products, DF-110D
- Pelron Corporation, P-463
- Nalco, 72028
- Dow, Polyglycol 45-200
- Dow, Polyglycol FR-530
- Dow, Polyglycol P-1200
- Dow, Polyglycol 112-2
- Dow, Polyglycol P-1000TB
- Dow, Polyglycol P-2000
- Dow, Polyglycol P-4000
- PPG, MAZU-DF-04

The following agents are not compatible and should not be used:

- O'Brien Products/Zinkan Enterprises, O'B No Foam 24
- Surpass Chemical Co, Nofoam AK
- Ultra Additives Inc, Foamtrol WT-2
- Ultra Additives Inc, Foamtrol WT-73
- Ultra Additives Inc, Foamban MS-5
- Brose Chemical C, BCC-336
- Drew Chemical, Drewplus L-674
- Betz, Foamtrol AF1660
- Betz, Foamtrol AF3550
- Betz, Foamtrol AF3551

9.6 Appendix: Device List

The following is a list for recommended devices for:

- pump driven permeate extraction:

1. Permeate pump reversible + VFD controlled (serves for the backwash process and MCP cleaning)
2. Permeate flow meter (bidirectional)
3. Pressure sensor in permeate line (digital with display)
4. Air blower for MBR cross-flow + VFD controlled
5. Air flow meter (digital)
6. Pressure sensor in air line (digital with display)
7. Temperature sensor in air line
8. pH / temperature sensor filtration tank
9. MLSS sensor filtration tank
10. Level sensor in filtration tank (pressure or ultrasonic)
11. Pump for sludge recirculation (not required for internal configuration)
12. Venting tank
13. Permeate tank
14. Motor control valve for permeate line
15. Motor valve for backwash and degassing
16. Chemical storage tank (NaOCl)
17. Chemical storage tank (citric acid)
18. Chemical dosing pump (DP) NaClO
19. Chemical dosing pump (DP) citric acid
20. Manual valve with hand operation for the permeate line (one per module)
21. Manual valve with hand operation for the air line (one per module) - steel
22. Motor/solenoid valve for chemical (NaClO) dosing pipes
23. Motor/solenoid valve for chemical (citric acid) dosing pipes
24. Level sensor for permeate tank
25. Turbidity sensor for permeate tank

- pump operated permeate extraction:

1. Permeate flow meter (bidirectional)
2. Pressure sensor in permeate line (digital with display)
3. Air blower for MBR cross-flow + VFD controlled
4. Air flow meter (digital)
5. Pressure sensor in air line (digital with display)
6. Temperature sensor in air line
7. pH / temperature sensor filtration tank
8. MLSS sensor filtration tank
9. Level sensor in filtration tank (pressure or ultrasonic)
10. Pump for sludge recirculation (not required for internal configuration)
11. Venting pipe
12. Permeate tank
13. Motor control valve for permeate line
14. Motor valve for backwash and degassing
15. Chemical storage tank (NaOCl)
16. Chemical storage tank (citric acid)
17. Chemical dosing pump (DP) NaClO
18. Chemical dosing pump (DP) citric acid
19. Manual valve with hand operation for the permeate line (one per module)
20. Manual valve with hand operation for the air line (one per module) - steel
21. Motor/solenoid valve for chemical (NaClO) dosing pipes
22. Motor/solenoid valve for chemical (citric acid) dosing pipes
23. Level sensor for permeate tank
24. Turbidity sensor for permeate tank