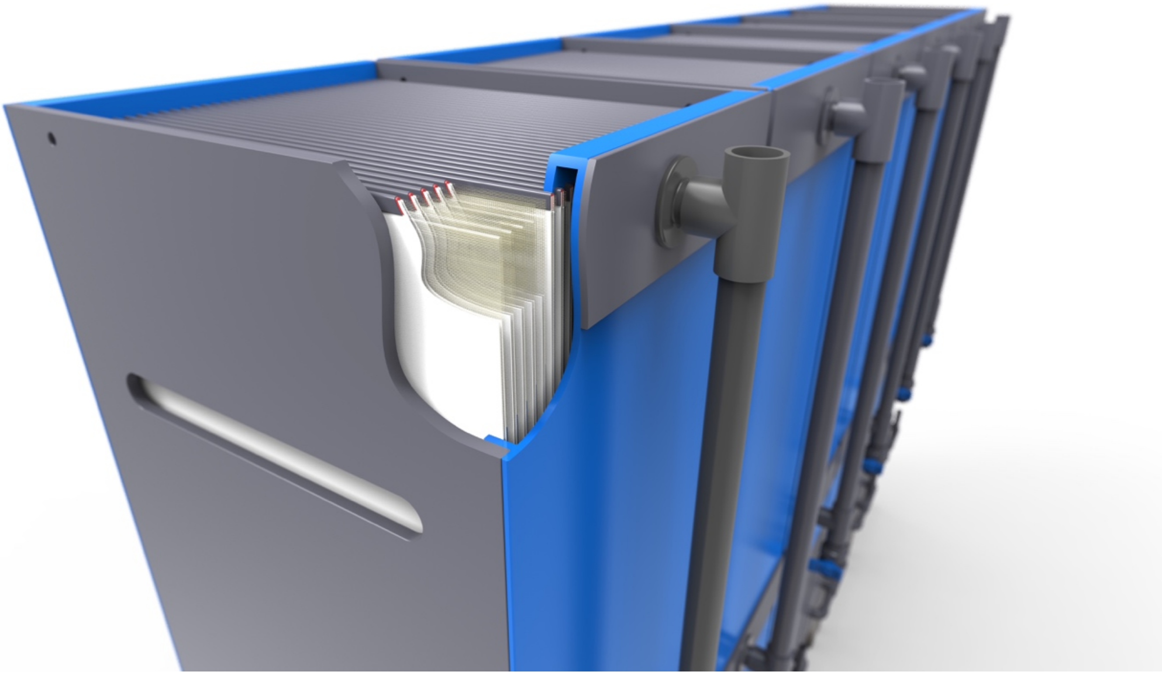
Design, Operation and Maintenance Manual for Membrane Bioreactors applying IPC® Membrane Technology



Version 5.0 – June 2020

Preface

This manual, published by **Blue Foot Membranes N.V.,** introduces general design and operational procedures for membrane bioreactors (MBRs) applying IPC® membrane module technology by its clients. Besides safety regulations and general procedures for IPC® module technology, basic design concepts about membrane bioreactors are described.

Non-observance of the instructions regarding the use, operation and handling of IPC® membrane modules can lead to expiration of warranty.

Detailed operation is presented in the document “General guidelines for the correct use of IPC® Membrane modules”.

In individual cases, a specific addendum to the “General guidelines for the correct use of IPC® Membrane modules” is added as agreed upon with clients.

This manual does not substitute a personal instruction by specialists and operational staff.

In this manual the following security symbol will be used:

This symbol highlights that, in case of non-observance of the safety instructions, risks arise which may severely endanger/injure service staff, damage or destruct the membrane module or lead to environmental pollution.

In case of questions or problems concerning the IPC® technology provided by Blue Foot Membranes N.V., please contact; **Blue Foot Membrane N.V. / Gerard Mercatorstraat 31 / B-3920 Lommel, Belgium / Email: info@bluefootmembranes.com**

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1 Integrated Permeate Channel (IPC®) Membrane Module

1.1 IPC® membrane

The individual membrane envelopes are comprised of a 3D spacer fabric and coated with a PVDF membrane on both sides (Figure 1).

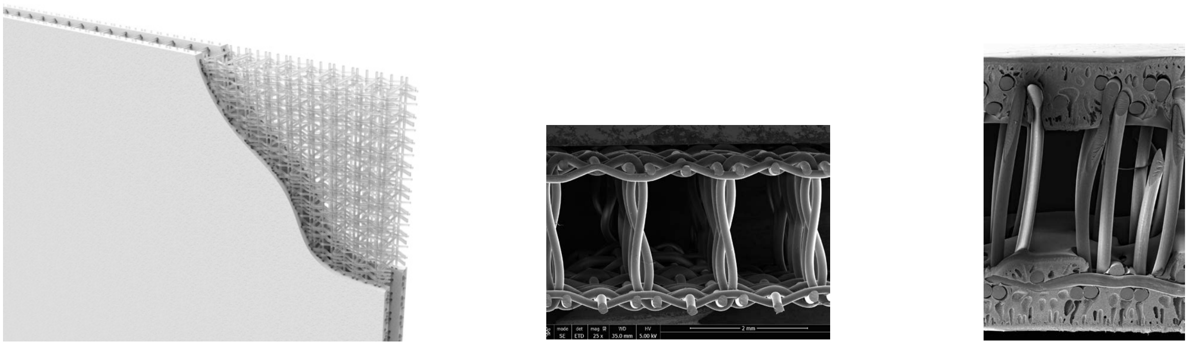


Figure 1: IPC®-membrane envelope

Table 1: IPC®-membrane data

Membrane Data		
Membrane material		PVDF
Nominal pore Size	µm	0,04
Maximum pore size**	µm	0,08
Average Permeability	l/m²*h*bar	1.500
Flux rate, activated Sludge	l/m²*h	15 - 50
Concentration, activated sludge MLSS	g/l	8 - 15

1.2 IPC® filtration module description

The IPC®-membrane modules (
) are flat sheet membrane modules, which are constructed by many parallel-arranged membrane envelopes with defined distances between these envelopes. The envelopes are fixed within side-headers, in which the filtrate of the individual envelopes is collected and discharged.

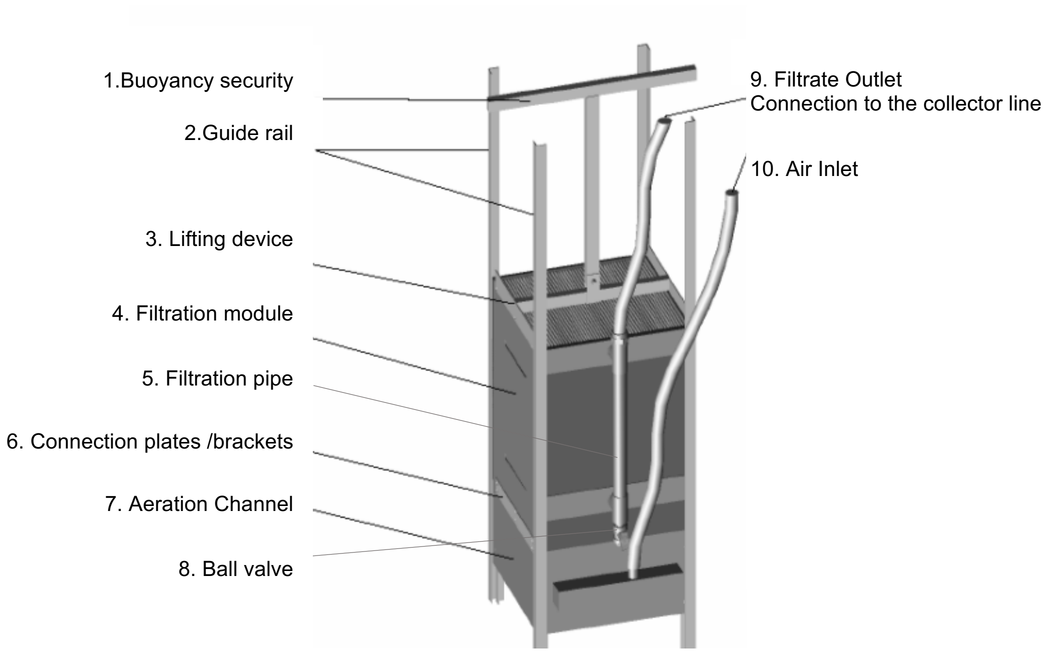


Figure 2: IPC®-membrane module

1. Buoyancy security	Avoids lifting of the modules during installation, they are filled with air originally.
2. Guide rail	Guides the module in place
3. Lifting device	Enables loading and un-loading of the modules in the filtration basin using a hoist or crane
4. Filtration module	Submerged ultrafiltration membrane module
5. Filtration pipe	Permeate collection pipe
6. Connection plates	Holds the aeration device and the module connected (using screws)
7. Aeration unit	Fine bubble aerator device
8. Ball Valve	blind of for single module design or connect permeate line when using stacks
9. Permeate outlet	Connection to the permeate collector line
10. Air inlet	Supply of air to the aeration system

1.3 Single-deck modules for MBR applications

Table 2: Single-deck modules for MBR applications

Module Type		IPC® - 7	IPC® - 25	IPC® - 75	IPC® - 80	IPC® - 90
Operating data						
Operating pressure	mbar	20 - 350				
Temperature range	°C	5 - 50				
Backwash pressure	mbar	< 1000				
Membrane Data						
Membrane material		PVDF				
Nominal pore Size	µm	0,04				
Maximum pore size**	µm	0,08				
Average Permeability	$l/m^2*h*bar$	1.500				
Flux rate, activated Sludge	l/m^2*h	15 - 50				
Concentration, activated sludge MLSS	g/l	8 - 15				
Module Data		**IPC® - 7**	**IPC® - 25**	**IPC® - 75**	**IPC® - 80**	**IPC® - 90**
Brut Membrane Surface	m^2	7	25	75	80	90
Net Membrane surface	m^2	6,8	23	70	75	85
Membrane plate distance	mm	9	9	9	8	7
Number of membrane sheets		12	28	54	59	65
Module material		PUR , PVC				
Module Dimensions		**IPC® - 7**	**IPC® - 25**	**IPC® - 75**	**IPC® - 80**	**IPC® - 90**
Width	mm	185	385	736	736	736
Height	mm	1090	1058	1070	1070	1070
Height with aeration Channel	mm	1510	1748	1810	1810	1810
Depth	mm	316	466	716	716	716
Depth with filtration pipe	mm	343	562	825	825	825
Weight, dry	Kg	30	45	130	140	150
Weight, wet (estimate)	Kg	65	90	280	280	280
permeate connections		2	2	2	2	2
Filtration pipe diameter	DN	15	20	50	50	50
Aeration						
Design		Tube diffuser				
Number tubes		1	3	5	5	5
Material		Silicone				
Aeration demand / module	Nm^3/h	4,8	16	48	48	48

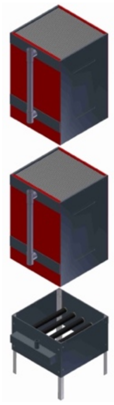
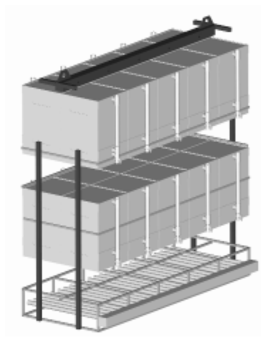
* estimater out of Porometer data

** measured by Porometer

1.4 Multi-deck modules for MBR applications

Table 3: Multi-deck modules for MBR applications based on IPC®-80 module

		Double deck	Multi- deck			Multi deck	
Module type		**IPC®-80-002**	**IPC®-80-003 MM-3-1-z-001**			**IPC-80®-003 MM-5-2-z**	
Module data							
Membrane material		PVDF					
Membrane surface (approx. data)	[m^2]	160	Z=1 240	Z=2 480	Z=3 720	Z=1 800	Z=2 1600
Material module		PUR, PVC, PP					
Grouting		Plastics					
Module housing		Protective plates PVC					
		Double deck	**Multi- deck**			**Multi deck**	
Module type		**IPC®-80-002**	**IPC®-80-003 MM-3-1-z-001**			**IPC-80®-003 MM-5-2-z**	
Dimensions							
Width	[mm]	736	2425			3710	
Height	[mm]	2140	Z=1 1070	Z=2 2140	Z=3 3210	Z=1 1070	Z=2 2140
Height with aeration channel	[mm]	2880	2350	3420	4490	2350	3420
Depth	[mm]	716	716			1432	
Depth with filtration pipe	[mm]	825	825			1650	
Weight, dry[1)]	[kg]	280	Z=1 480	Z=2 960	Z=3 1480	Z=1 1600	Z=2 3200
Weight, filled/wet[1)]	[kg]	560	1500	3000	4500	5000	10000
# connections		4	6	12	18	20	40
Filtration pipe diameter	[DN]	50	50			50	
Aeration							
Design		Tube diffuser					
# tubes		5	15			50	

Material		Silicone					
Aeration demand / module	[Nm³/h]	48	144	144	144	480	480
Aeration bubble size		medium-sized bubbles					
Picture							
							

[1)] Weight without aeration unit

2 Safety instructions

The security installations, which were installed at the machine by the manufacturer, are just the base of the industrial safety. The main responsibility to guarantee an accident-free operation has to be taken on by the operator and its trained staff.

Only proper and intended handling and the compliance with the requested maintenance procedures can guarantee the functionality and a long lifecycle of the membrane modules and of all the parts of the installation. Moreover, proper and intended handling will help to avoid any industrial accident.

The staff performing the operation and the maintenance of the filtration plant has to have read and understood this manual. All the instructions mentioned in this manual should be followed together with the document “General guidelines for correct use of IPC membranes in MBR applications”. In particular cases, a project specific addendum is added to the above document as part of the commercial agreement. **In this case the guidelines in the addendum overrule the “general guidelines”.**

In order to guarantee a high system security and to avoid any industrial accidents, only authorized and well-trained staff should be instructed in handling the installation. A technical briefing of potential risks which may occur during the operation of the installation should have been given to the staff.

The manufacturer will not be liable for personal injuries resp. material damage caused by improper handling or by non-observance of the mentioned security advices. This risk will only be covered by the owner resp. the operator of the installation.

An operation of the membrane modules, varying of the hints mentioned in this manual, will cause the loss of any warranty right.

Please always consider: Safety first!

2.1 Personal Health & Safety

- For any type of equipment used during installation, operation or maintenance on the modules, ensure personnel are qualified and trained to operate the equipment.
- Keep the working space around the MBR clean and clear at all times; good housekeeping will prevent injury from slipping and falling.
- When modules are installed, take proper precautions for working at heights.
- Modules may be heavy. Take proper precautions (e.g., safety boots...) to prevent injuries.
- When working with chemicals, always wear safety glasses/goggles and gloves.
- When working with chemicals, ensure to be familiar with the Material Safety Data Sheets (MSDS) of the chemicals in use at the site.
- Do not mix incompatible chemicals that may lead to formation of hazardous or lethal gases (e.g. chlorine gas).
- Watch out for mixing of Alkaline and Acid mixing solutions

2.2 Module Safety

- Avoid working with sharp tools, extreme care must be taken not to expose membrane case to welder or grinder sparks.
- Make 100 % sure that the filtration tank does NOT contain contaminants or sharp-edged items, like cable slips, swarf or wires.
- Ensure that no materials can fall into the top of the membrane module during installation, it is strongly recommended to leave a part of the plastic protective packaging over the module during the module installation in an empty tank until the tank gets filled.
- Move the module only by using the lifting device. NEVER use the filtration pipe as a carrying handle!
- The module must not be installed by use of force! Avoid any kind of blows affecting the module, e.g. hammer blows!
- The module must be protected against unintended fall during the installation process! Multimodules must be protected against toppling.
- When moving a multimodule, a cross beam has to be used. The fastening of a multimodule using chains and belts is expressly prohibited!
- The dipping and immersion of the modules must be carried out with open collector line with direct connection to the atmosphere in order to guarantee the captured air to be exhausted!
- The modules must be fixed in the tank against buoyancy using a buoyancy security rail!

- The module must be SMOOTHLY lifted out of the water in order to allow the modules to discharge during this lifting procedure.
- The modules have to be stored in a proper way and drying has to be avoided. Drying of the membrane surface can destroy the module.
- When lifting IPC® modules outside of the membrane tank, be aware that the **wet weight of the modules will be double the dry weight** mentioned in the product specification in case the membrane channels are filled with sludge.

2.3 Operational Safety

- The membrane surface must not be cleaned by hand or with sharp or abrasive active items! Do not use a high-pressure waterjet for the cleaning procedure as this damages the membrane surface!
- Keep membranes wet at all times after first time of use. Irreversible damage may occur if membranes dry out.
- When preparing cleaning solutions, ensure that all chemicals are dissolved and well-mixed with the filtrate before backwash of the membranes.
- For chemical cleaning of element, it is important to select the suitable chemicals in accordance with the type of adherent contaminant. Using the wrong chemicals may cause poorer filtration performance or damage the element.
- When backwashing with cleaning solutions, note the allowable temperature and pH limits.
- Ensure sufficient de-aeration of the filtrate pipe when backwashing the membranes, to prevent air entrapment in the membranes.

2.4 Environment

- Disposal of cleaning chemicals should comply with local regulations and best practices.
- If due to operational reasons, the usage of hazardous material is necessary, please respect the requests of the national / local directives.

3 Basics of membrane bioreactors operation

3.1 Basics of the biological wastewater treatment

The common attribute of all types of biological wastewater treatments is the degradation of the solids caused exclusively by the metabolism activity of the micro-organism. During this biological reduction process, the micro-organisms oxidise the solids. Besides the biomass production (cell growth) by the metabolism, biomass gases (e.g. elementary nitrogen) which will exit to the atmosphere will be produced. Therefore, in wastewater treatment plants there are operated aerated and non-aerated reactors which will eliminate the nitrogen (nitrification and denitrification) and carbon.

The membrane bioreactor (MBR) is a combination of the activated sludge process and the membrane technology; After the biological degradation process, the biomass (activated sludge) is not isolated by the conventional sedimentation process in the clarifier, but by a porous membrane filtration. Due to the small pore size, the membrane is not only a barrier for the activated sludge, but also for suspended substances and bacteria. Small species like dissolved or colloidal organics and viruses will be adsorbed on the particulate matter outside of the membrane and as such are excluded significantly from the filtered water. As a result, a high quality of the effluent is produced.

Parameters for the characterisation of wastewater are presented in Annex 1.

3.2 Operational parameters for MBR

The operation conditions of the IPC® membrane bioreactor modules are provided in Table 4. For exceptional feedwater quality and applications, please consult Blue Foot Membranes N.V.

Operational Parameter	Unit	Value
Temperature range:	ºC (ºF)	5 – 50 (41–122)
Typical Filtration Trans Membrane Pressure:	mbar (psi)	20 – 500 (< 0.29 – 7.25)
Maximum Backwash Trans Membrane Pressure:	mbar (psi)	1000 (14.5)
pH range during normal operation	—	5 – 9
Allowable pH range (for cleaning):	—	2 – 11 (Max 30°C)
Typical Mixed Liquor Suspended Solids concentration range:	mg/L	8,000–15,000
Flux range	l/(m^2.h) (gal/(ft^2.d))	10–50 (6–30)
Maximum peak flux / Maximum Backwash flux	l/(m^2.h) (gal/(ft^2.d))	100 (60)
Air demand / Module or stack (IPC 80)	Nm^3/h	48

Table 4: Standard operating conditions of the IPC® membrane bioreactor modules

3.3 Design parameters and MBR process configuration

3.3.1 Design Parameters

The following characteristics should be taken into account for the correct sizing of an MBR design;

Capacity
The amount of permeate water produced for the system (Q, in m^3/day).

Peaking Capacity
Peak amount of permeate water produced for the system (Q_{peak}, in m_3/day).

Dissolved Oxygen
The amount of Oxygen that is dissolved in the system and available for biodegration. The membrane tank of the MBR should have a minimum of 1 ppm dissolved oxygen in order to be in a good operation condition.

Food to micro-organism ratio
The F/M ratio is a process parameter commonly used to characterize the operating conditions and presents the BOD F/M in g substrate / g biomass. It is defined as the rate at which the solids are fed into the tank compared to the mass of the reactor solids (in 1/T), typical values are 0,05-0,2 Max.

Hydraulic retention time
The HRT is the time average residence time of liquid in a tank; the volume of the tank / by the volumetric flowrate in hours. Typical HRT values for MBR are typically >3-5 hours, where 3 hours is a minimum.

Return activated sludge
The RAS is the return flow from the membrane tank to the aeration basin of an MBR. In some design it might be returned to the aerobic or anoxic zone.

Solids retention time
The SRT represents the average periods of time during which the sludge has remained in the system or mean cell retention time. This is expressed in days and is typical between 18-25 days but can be between 10-40 days. Controlling the SRT determines the rate of substrate degradation, nitrification, excess sludge production a biomass concentration.

Temperature
While operating a biological wastewater treatment installation attention needs to be paid to the temperature as it strongly affects the metabolism of the micro-organisms. Extreme (too low or too high) temperatures may negatively harm the biological degradation process and may even destroy the biomass in the reactor. The optimized temperature for a biological wastewater treatment is set between 10°C and 30°C.

The water temperature also has a major impact on the maximum allowable membrane flux, due to the fact that the trans membrane pressure is proportional to the water viscosity. $J = J_{20}\,1{,}025^{(T-20)}$.

Peak flow management

It is important to consider management of flow fluctuations caused by both diurnal variation and storm events for municipal MBRs and process variation and seasonal waste production variation for industrial or mixed feed MBR installations. MBR designers, in general, have 4 options for handling peak flow conditions:

1. provide sufficient membrane area to treat peak flows;
2. select a membrane configuration that has a higher operational window and degrees of freedom on flux and peak flow management (like IPC®);
3. provide equalization volume upstream of the membranes,
4. provide a hybrid design where the MBR is operated in parallel with another unit operation.

3.3.2 Configuration of biological reactor

The biological process design for an MBR uses the same design principles as for a CAS plant except that MBR's typically operate at a higher MLSS concentration and shorter hydraulic retention times (HRT's). For a given biomass inventory, an MBR can be operated at higher MLSS concentrations and with a smaller aeration basin volume and plant footprint. Total nitrogen and phosphorous removal (BRN) are possible but will not be discussed here. Standard average MLSS concentration varies between 8000 and 15000 mg/l which is significantly higher compared to conventional WWTPs (factor 2 - 4).

The necessary volume of the activated sludge tank is mainly influenced by the sludge loading and sludge age. Oxygen transfer also influences the basin size. When operating at higher MLSS concentration, sufficient biological mass can be maintained for complete treatment with a short hydraulic retention time (HRT). However, the associated oxygen demand may be beyond the capability of the diffused aeration system, requiring a larger basin to ensure the ability to meet the oxygen demand.

3.3.3 Solids and hydraulic retention times

Historically, most of the municipal membrane bioreactors are operated with a sludge age of 25 days (SRT) and are considered as installations with aerobic sludge stabilisation. More recently shorter SRT' s are used to design MBR's.

A minimum HRT is required to allow adsorption and synthesis of constituents before exposing them to the membranes. Experience has shown that a minimum HRT of 3 hours is required to allow influent colloidal matter to be adsorbed into flocs before reaching the membrane.

3.3.4 Mixed liquor suspended solids

MLSS is the concentration in mg/l of activated sludge. Concentrations of 8000 to 15000 mg/l are considered normal for MBR operation. The higher the MLSS concentration in the wastewater, the lower the oxygen transfer coefficient (K_La) becomes.

As a result, at higher MLSS concentration in an MBR requires more aeration to deliver the same amount of oxygen. It is common for the oxygen uptake rate to control the size of the aeration basin as discussed above.

Unlike in CAS systems, settleability of the sludge is not of major concern but sludge filterability is. This is a measure for sludge quality and may be an indicator of membrane fouling and cleaning requirements. Sludge filterability may be affected by fines and colloidal matter in the mixed liquor, as well as elevated concentrations of EPS (extracellular polysaccharides), floc size and floc characteristics.

3.3.5 Return activated sludge recirculation

As the growth of the micro-organisms is concentrating the activated sludge, and as the membrane operation with in the MBR is extracting water, the additional sludge (excess sludge) has to be removed out of the membrane tank system in order to operate the system under a constant sludge loading. MBR's require a higher RAS than CAS systems, typically 4 to 5 times Q (Q=the permeate rate). The main purpose is to redistribute the solids in the biological system and to prevent accumulation of solids in the membrane tank.

High RAS rates will result in a lower HRT than in a conventional process which requires attention to kinetics and reactor design to avoid short-cutting and too low HRT's as discussed above.

3.4 Membrane feed-water quality and pre-treatment

When operating an MBR system, pre-treatment is essential for optimal membrane performance and is critical for the long-term performance of an MBR operation and prolonging the membrane life. A pre-treatment stage must eliminate particles and matters that can negatively influence and/or damage the filtration process,

When pre-treating untreated water, all particles and wastewater components that may damage the membrane, modules or other parts of the plant must be removed from the untreated water. Especially hairs, fibres and fats and oils in high concentrations will provoke clogging on the membranes. All materials that may damage the membrane by causing high mechanical stress or by having sharp angles (e.g. such as unwanted/unintended construction debris, abrasive solids) should be removed first.

It must particularly be ensured that the pre-treatment process cannot be bypassed in case of malfunctioning of the sieving process. Under all circumstances it should be avoided that sewage/wastewater, which has not undergone adequate pre-treatment, could enter the membrane tank.

Design and selection of the pre-treatment system is application specific and may include; grit removal, grease removal, coarse and fine screening, primary clarification, equalization and other methods of peak management.

3.4.1 Rakes and screen

For eliminating bigger pollutants and fibres from the inlet, the installation of screens or sieves is absolutely necessary. A classification of screens/sieves according to their mesh size is listed in **.**
Table 5.

Table 5: Classification of screens or sieves

Type of screen	Mesh size
coarse rack	> 50 mm
strainer rack	10 mm – 20 mm
sieve	< 10 mm – 1 mm
fine sieve	< 1 mm

Effective fine screening is critical for MBR systems to protect the membranes from damage as well as prevent clogging of membrane channels. Properly designed, operated and maintained fine screens reduces the need for membrane maintenance and prolong the membrane life. All MBRs require an influent screen of 1-3 mm opening. Screens must have no potential to carryover solids! Typically used screens in MBR systems are; centre-feed band screens, rotary drum screen, rotary basket screens and micro screens. Bar and wedged wire screens are not effective and should not be used as they allow fibrous materials to pass.

Rake screens at the headworks are generally not recommended to serve as fine-screen protection upstream of a MBR system, because the combination of the flow through the MBR tank is typically 4–5 times higher than the influent flow, and the MLSS concentration will put a large demand on the fine screen.

3.4.2 Grit and grease removal

In the grit chamber (and/or the grease separator) the flow-velocity of the wastewater is reduced in order to allow the sedimentation of (mineral) solids. A roll-flow is established by aerating the grit chamber/ grease separator. A scum baffle is installed in the tank in order to accumulate the grease components of the wastewater in a flow-depressed area of the tank. The installation of a grit chamber/ grease separator is necessary in order to protect the membranes and pumps. Grit can be detrimental to MBR operation in two ways; by accumulation in the aeration basin / membrane tank and by potential abrasion of the pumps and membranes.

Fats, oils and greases (FOG) removal should be considered based on an understanding of the influent quality. Grease should be removed to protect the fine screens from clogging and the membranes from fouling. The membrane manufacturer needs to be contacted if high levels of FOGs (>100 ppm in the influent of the MBR) are expected, in order to discuss the effects and a mitigation plan.

3.4.3 Toxicity

When toxic components are present in the wastewater, this may harm or kill the biology in the aeration tank, leading to a poor sludge quality and membrane clogging.
Ensure that the influent wastewater is free from elevated levels of toxic components. Pre-treatment may be required to remove toxic compounds from the MBR feedwater.

3.4.4 Flow equalization

Flow equalization to manage peak flows and positioning of the fine screens downstream of the primary clarification can significantly reduce the cost of fine screens and screening handling equipment.

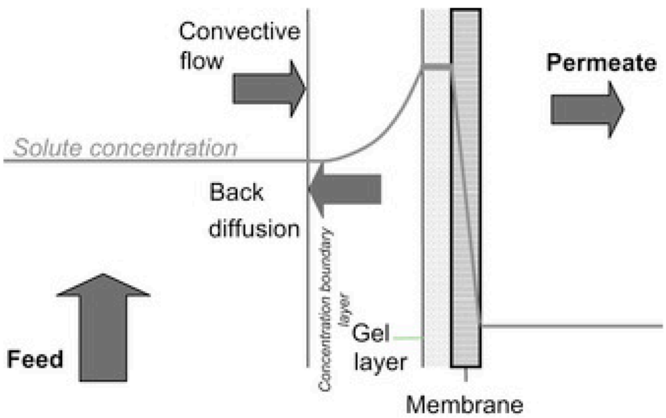
3.5 MBR operation cycle and cleaning strategies

3.5.1 Introduction

In order to guarantee the performance of the membranes, methods for removing the cake layer during membrane filtration from the membrane surface must be considered. Two types of fouling are observed:

- Physical fouling - substances which can be released mechanically
- Chemical fouling - substances which can just be released by use of chemicals

In MBRs, the balance between the flux and the physical and chemical cleaning protocols control of the concentration polarisation (CP) which will ultimately determine to what extend fouling is fully suppressed. Two methods can reduce CP related fouling: 1) promoting turbulence at the membrane/ liquid interface (which decreases the thickness of the boundary layer and improves transport rate across), 2) reducing the flux.



Physical cleaning to remove particles and substances mechanically from the membrane surface and out of membrane pores (“reversible fouling”) by two ways; 1) creating turbulence at the membrane surface through coarse bubble aeration and 2) physically remove blockages and disturb the CP layer by backwashing /or back pulsing permeate though the membrane in the inverse direction (inside – out). Physical cleaning is less time consuming (between 30 sec and 2 min depending on the operation cycle) and it demands no chemicals and is less likely to cause membrane degradation.
Relaxation is used mainly in flat sheet MBR modules that operate without backwash and is meant for the cake layer to expand and to be removed more easily.

Chemical cleaning is carried out using mineral or organic acids, caustic soda and mostly using sodium hypochlorite. These cleanings dissolve organic /inorganic species that are present on top of the membrane and in membrane pores ("irreversible fouling") and can be performed in situ, called "Cleaning-in-place" (CIP), or ex situ. Alternatively, a lower concentration of chemical cleaning agent is added to the backwash water to perform a "chemically enhanced backflush" CEB, usually performed only periodically.

3.5.2 Filtration cycle - Theory

Since flux influences the permeability decline rate dK/dt (or pressure increase dP/dt, Figure 3), it also determines the period between backflushing and as such the physical cleaning cycle time (t_c) expanding multiple filtration cycles. When backwash is used, the backwash time is t_b and increasing the flux will decrease t_b. So, at higher operational fluxes, a higher backwash frequency is required. To obtain an effective backwash operation, the inverse flux (flow rate) should be about 2 times the filtration flow rate in IPC® modules.

Since backwashing does not recover the permeability fully to the original condition, only a finite amount of backwashes can be performed before a threshold pressure is reached P_{max} beyond which operation cannot be sustained. At this threshold pressure, chemical cleaning must be conducted to return to the pressure, close to the original baseline value. The cleaning solution stays for a defined time within the membrane while soaking it. The time span depends on chemical concentration, temperature, type of fouling, etc. Afterwards, the substances „pre-dissolved" in this way will be removed completely from the membrane either by the shear forces caused by the ascending air or by a short backflow of the permeate.

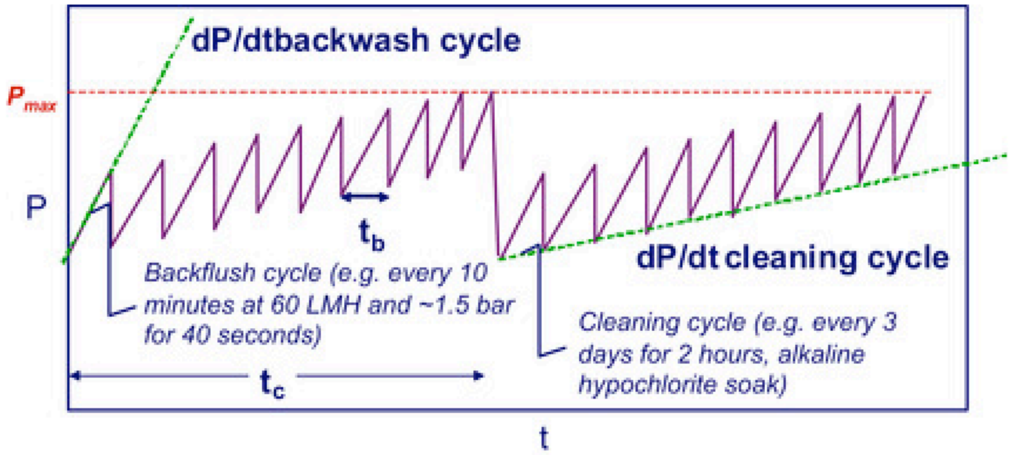


Figure 3: Pressure behaviour as a function of time during MBR Filtration

IPC®-membrane modules should only be used for the intended application area of wastewater treatment, drinking and process water preparation and effluent polishing.

Every modification by the client regarding the membrane modules or the utilities and cleaning chemicals must be communicated and confirmed by Blue Foot Membranes N.V. Every non-authorized procedure may result to the loss of warranty.

3.5.3 Operational flux

The necessary membrane surface is achieved by the ratio of the maximum inlet flow (peak flow) to the max. permeate flow during peaking.

$A_{membrane} = Q_{inlet} / F$

$A_{membrane}$	= Effective membrane area (m^2)
Q_{inlet}	= Average daily flowrate (m^3/day)
F	= Design flux rate (m^3/m^2.day)

The design flux rate depends on type of wastewater, MLSS concentration, influent strength, temperature etc. Using IPC®-modules in an MBR with municipal wastewater an operational flux of 20-40 L/(m^2*h) is achieved. For peaking, generally 50% -100% higher can be achieved for a short duration. As a result of the filtration / backwash / relaxation cycle, the net flux is 10-25 % less compared to the gross flux. This results in an overall feed water recovery of 90-75 % respectively depending on the selected operational cycle. On average, the overall mean value of the filtrate volume stream should equal the inflow volume stream.

The cyclic operation is needed for a minimization of the cake layer. The backwash removes the cake layer from the membranes surface. During relaxation the detached particles can easily be removed from the module by the crossflow provoked by the aeration device.
A typical filtration cycle is characterized by:

- a filtration cycle ranging between 4,5 – 20 min., followed by
- a backwashing cycle of minimum 15 seconds up to 2 minutes whereby the backwash flux = 1,5 – 2 x operational flux, followed by
- a short relaxation cycle (without filtration) of maximum of 10 -20 seconds.

→ Operational pressure should remain < 0.5 bar (suction pressure).
→ Backwash pressure should be < 1 bar.

Net flux is calculated by the difference of the operational flux multiplying by the filtration time and the backwash flux times the backwash time all within one hour. Alternatively, the net flux within one cycle can be calculated by the difference of the operational flux multiplying by the filtration time and the backwash flux times the backwash time all within one cycle, divided by the sum of the filtration time, the backwash time and relaxation time.

The net flux is calculated as follows;

$$J_{net} = n\frac{(Jo.tf - Jb.tb)}{(tf+tb+tr)}$$

Where

J_o = Operational flux in $l/m^2.h$

J_b = Backwash flux in $l/m^2.h$

t_f = Filtration time

t_b = backwash time

t_r = relaxation time

3.5.4 Physical cleaning

3.5.4.1 Aeration

IPC® membrane modules are positioned above an aeration system using either fine bubble or coarse bubble aerators. This aeration is on for 100% of the time and is one of the most important operational aspects of a well running MBR system. The function of the air bubbles to create turbulence and "wakes" causing an elevated shear rate near the water membrane interface. This shear rate is needed to minimize the thickness of the concentration polarization layer and to disturb the cake layer that is build up on the membrane surface as a result of the filtration.

3.5.4.2 Backwash

As explained above, the higher the operational fluxes, the higher backwash frequency is required. To obtain an effective backwash operation, the inverse flux (flow rate) should be about 2 times the filtration flow rate in IPC® modules. IPC® modules are fully back washable which means that at high rate back pulsing is possible to achieve high operational fluxes during biological upsets, peak flows.

3.5.5 Chemical cleaning

3.5.5.1 Maintenance-cleaning or Chemically enhanced Backwash (CEB)

A maintenance-cleaning for municipal MBR's is typically arranged every 7-14 days after the commissioning. For other types of wastewater, the interval has to be adapted. During the maintenance-cleaning there will be a permeate/cleaning chemical mixture (low concentration of the chemical liquid) pumped in the membrane similar to the backwash flow (in the opposite direction to the standard operation direction, however at 1 time the forward flow). This mixture is left in the membrane envelopes to soak the membranes. During the soaking time (30 min – 1 hour) a part of the low-concentrated cleaning solution will diffuse through the membrane. So the "pre-dissolved" layer will be removed from the membrane. After the soaking time, the cleaning solution will be evacuated out of the membrane by changing to the standard operation (change of flow-direction). The sequence of cleaning chemicals used, is mostly alkaline cleaning, (most common sodium hypochlorite) followed by organic acid (citric acid most commonly used). The reasoning is that finishing with an alkaline cleaner can promote precipitation of metal hydroxides and carbonate salts. That is why finishing with an organic acid is recommended to dissolve mineral salts and inorganic precipitates as the last step.

Standard maintenance clean for municipal wastewater:

cleaning frequency:	every 7-14 days after commissioning
back wash flux:	reduced to 1-time operational flux
back wash volume:	2 x dead volume of piping and internal module volume
soaking time:	30 -60 min
chemicals:	sodium hypochlorite with 0.02 % free chlorine; diluted (200 ppm); pH 9-10
Followed by:	Organic Acid (citric acid) at a concentration of 500-1500 ppm

3.5.5.2 Recovery-cleaning / Cleaning in Place (CIP)

Chemical cleaning of membrane elements should be conducted when the transmembrane pressure rises to excess. Such a pressure increase is caused by fouling that clogs the pores of the membrane surface. The timing of chemical cleaning should be determined as follows:

1. Every 6 months or when the transmembrane pressure has risen by 5 kPa / 50 mbar from its initial operating level at the same permeated water flow rate, whichever earlier.
2. The early chemical cleaning is effective to remove contaminants clogged in the membrane pores.
3. In the case that the transmembrane pressure raises by 5 kPa within 3 months, observe how many weeks/months it takes for the transmembrane pressure to rise by 5 kPa and conduct chemical cleaning periodically. This measure is effective in prolonging the life of membranes. The cleaning interval may be changed due to different process conditions.

During the so-called recovery cleaning or CIP, the modules remain in the filtration tank and will be cleaned most times in 2 steps.
First an alkaline cleaning solution is pumped from the permeate side into the membranes. The cleaning chemicals added remain within the membrane pouches for the duration of the reaction time (= soaking time), during the soaking time the membrane module is aerated for a short time (to mix the cleaning solution thoroughly). Then the used cleaning solution is drawn off again (filtration operation) and fed back into the cleaning container.

In a second cleaning step the procedure can be repeated with an acid cleaning solution.

Standard recovery clean for municipal wastewater:	
cleaning frequency:	at a transmembrane pressure of 200 mbar every ~ 3 to 6 months
back wash flux:	reduced to operational flux
back wash volume:	2 x dead volume of piping and internal module volume
alkaline soaking time:	usually 2 – 3 hours
cleaning chemical alkaline:	sodium hypochlorite with 0.08 % free chlorine, diluted (850 ppm), pH 10.5, T < 30°C
acid soaking time:	usually 1 - 2 hours
cleaning chemical acid:	citric acid < 2 %; alternative acetic acid or formic acid, pH 2 – 2.5, T < 30°

More elaborate cleaning options will be presented in the "General guidelines for correct use of IPC® modules in MBR applications".

3.5.5.3 External cleaning

External cleaning is performed in 3 steps. External cleaning tanks are used to perform this cleaning. The materials of construction of the tank, containers, pumps and piping needs to resistant to the cleaning chemicals used.

- First, for an external cleaning, the modules have to be dismounted and have to be rinsed by fresh water. Do not clean the membrane by a waterjet or a high-pressure hose as it will damage the membranes beyond repair. After the rinsing, the IPC® modules are ready for the next step.
- In the second step an alkaline cleaning solution is prepared in the external tank. The rinsed IPC® module is inserted in the cleaning reservoir filled up with the alkaline cleaning solution. Please make sure that the filtration pipe is installed and has a direct contact to the atmosphere. A recirculation should be created inside the reservoir provided by pump or by a cyclic aeration. After a soaking time of about 2 – 3 hours, the module should be removed out of the reservoir.
- In case of scaling deposits are present on the membrane surface, a third step is necessary to continue by an acidic cleaning procedure. First, the module has to be flushed from the inside of the lumen with fresh water. After that, the module is inserted again in the cleaning reservoir (now filled up with acidic solution). Should the same reservoir be used for alkaline cleaning, it is important to pay attention that no liquid of the previous cleaning remains in the reservoir. Otherwise, uncontrolled, dangerous chemical reactions can take place. After a soaking time of 1 – 2 hours the module is removed again out of the reservoir and can be reinstalled in the filtration tank and again operated.

3.5.5.4 Resistance to cleaning chemicals

The membranes are resistant to the following concentrations of cleaning chemicals:

Table 6: Resistance to cleaning chemicals

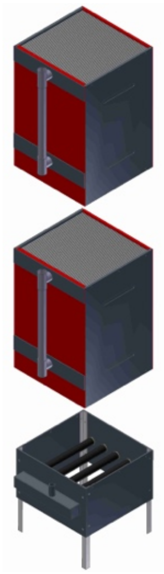
Cleaning chemicals	Concentration
pH (for all cleaning solutions)	2 < pH < 11 at a temperature of max. 30 °C
pH (for all cleaning solutions)	2 < pH < 10 at a temperature of max. 40 °C
H_2O_2	0,5 %
HCl	0,2 - 0,5 %
H_2SO_4	0,2 - 0,5 %
Citric acid	< 2 wt%
Acetic acid	< 2 wt%
Oxalic acid	0,2 - 0,5 wt%
Aspartic acid	0,2 - 0,5 wt%
Sodium hypochlorite	max. 0.2 wt% of active chlorine with a temperature from < 20°C for max. 3 h

The membrane has a service life of 350,000 ppmh of chlorine under the specified conditions.
For cleaning solutions which are not tested and confirmed by the **Blue Foot Membranes N.V.** there is given no warranty regarding the consistency of the membranes and the cleaning success.

4 Arrangement of the IPC® modules in a filtration reactor

4.1 Arrangement and construction of the modules

Basically filtration modules will be arranged in MBR installations as shown in Figure 4 A. The aeration unit is placed under the filtration module and will be fixed with connection plates on the filtration module. Above the filtration module the connection for the lifting device is screwed on. For flexibility reasons the collector line should be a tube line or hose. The membrane modules will be installed in guide rails. This must be done in such a way to prevent a lateral movement (slip) of the membrane modules (e.g. because the tank or the water moves). Furthermore, the guide rails must have lateral reinforcements in order to prevent bulging of the module wall when back flushing the module (counter bearings). A buoyancy security is needed at the top of the module to keep it in place and prevent vertical movement of the modules in the membrane tank. In order to remove the modules out of the tank, this buoyancy security has to be arranged above the water surface.



A

B

Figure 4: **A.** Construction of a membrane module incl. aeration unit, filtration module and lifting device – one storied (or single-deck) module (left) and 2-storied (or double-deck) module (right). **B.** Design of a Multi-module-system with three modules arranged next to one another and three modules arranged one above the other

A filtration unit may be a single-deck IPC® membrane construction or a multi-deck membrane construction, in which 2 or 3 modules are installed on top of each other.

Another possible arrangement is the multi-module, presented in **Figure 4** B. In this configuration, the aeration unit is integrated in the module frame where max. 9 membrane modules can be installed in total. As all the membrane modules can be dismounted in one set and as such, the installation/ disassembly effort is minimized. The main advantage of this arrangement is based on the compact construction, minimized space requirements and the centralized air supply.

4.2 IPC® module positioning in the membrane tank

The placement of the modules has to be completed by a crane, as the modules will be inserted from above in the activated sludge.

- It is required that the modules are totally submerged in the activated sludge liquid guaranteeing always a minimum sludge-coverage of the modules. A minimum 30 cm water head on top of the membrane is needed.
- In order to allow the formation of the necessary aeration roll-flow (down-comer), the footprint of the membrane tank should be double the size of the assembly-area (footprint) of the membrane modules (see examples below).
- The aerators need to keep a minimum distance of 30 cm to the basin floor and the module footprint of the side-by-side arranged modules must be equal to the face between tank floor and aeration unit.
- For the calculation of the minimum height of the tank, the minimum charging level (minimum 30 cm above the top header) and a safety factor for intense rain events (resp. mixing pond and equalizing reservoir) has to be considered.

Examples of membrane arrangements:

- Arrangement of the membrane envelopes parallel to the horizontal roll-flow (down-comer) direction
- Arrangement of maximum 2 module series parallel to the horizontal roll-flow direction

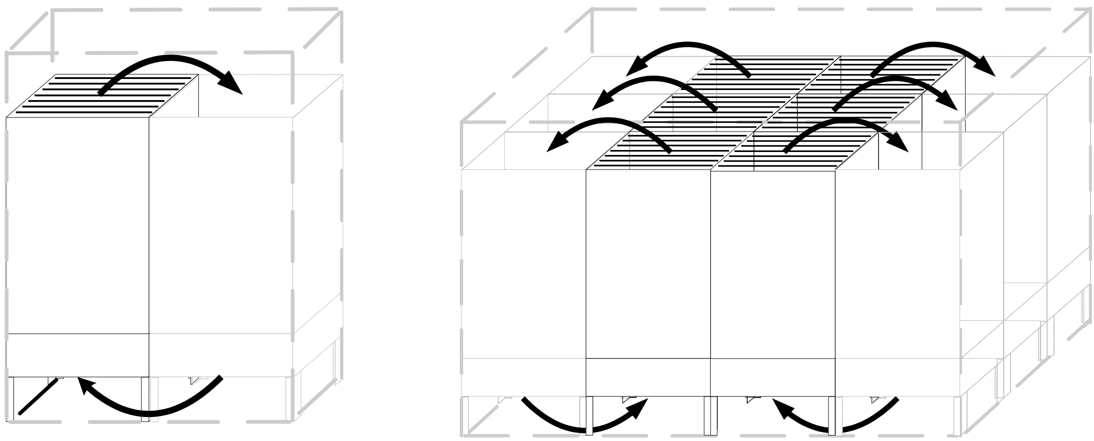


Figure 5: Examples of membrane module arrangements in a tank.

Varying module arrangements have to be confirmed by **Blue Foot Membranes N.V.**

4.3 Pumping technology of the filtration unit

For filtrate-pumps usually rotary piston pumps, eccentric screw pumps or self-priming centrifugal pumps are used as these pumps are easily adjustable and operate at constant flowrates and varying operational pressures. Also, positive displacement pumps are used as they are self-priming and allow pumping an air-liquid-mixture. Positive displacement pumps are bi-directional and can minimize equipment installation for small and average sized systems (e.g.: no pump exchange necessary during backwashing or CIP cleaning of the membranes). The resistance of the selected pumps to the chosen cleaning chemicals must be confirmed.

4.4 De-venting

A de-venting device must be integrated in the filtration line. This is of benefit when any build-up of air or gas is expected in the filtration line that cannot be eliminated by the pump alone. The de-venting device has to be positioned so that it ensures complete de-venting at the highest point of the permeate line.

4.5 Aeration

For the aeration of the IPC®-membrane modules Blue Foot Membranes N.V. offers a suitable aeration-aggregate. A self-designed aeration system has to be approved beforehand by Blue Foot Membranes N.V., in order to guarantee the functional efficiency of the modules. The aeration units are installed below the membrane modules by retaining plates and serve for the air scouring of the membranes and control of the cake layer thickness

The necessary aeration rate for each type of IPC®-membrane module is noted in the product specifications. The aeration rate is related to footprint of the module, 2 or 3 modules are installed on top of each other, the aeration rate will remain constant as the footprint is constant too.
To ensure proper aeration, the aerator cartridges in the aerator module must be checked regularly for proper functioning to ensure the homogeneous distribution of bubbles over the whole length of the cartridge. It is also recommended to do an optical inspection of the aerator cartridges periodically by pulling out the aerators. The lifetimes of the aerator cartridges can be very different depending on the wastewater.

They should be replaced regularly:

- Communal sewage water: every 2-5 years (depending on the condition)
- Industrial wastewater: every 1-3 years (depending on the condition)

- Different module assembly or self-developed aeration equipment must be cleared with **Blue Foot Membranes N.V.**
- Damaged aerators will lead to blocked membrane modules and can destroy the membrane modules!
  Aeration must work proper during filtration process.
- Insufficient aeration or non-even /insufficient air distribution over several modules will lead to blocked membrane modules and can destroy the membrane modules!
  Aeration must work proper during filtration process.

5 Handling and preparation of IPC® membrane modules.

Prior to commissioning, remove any impurities and contaminants caused by the installation and production process from pipes and tanks including substances that may be used during installation of the equipment or parts of the equipment.

5.1 Special precautions for storage and handling of the IPC® Membrane modules

1. During installation, it is highly recommended to leave the top side covered with carton or plastic to avoid debris, bolts... to fall into the membrane module and in between the membrane sheets, this will damage the membranes beyond repair.
2. The membranes must be installed in frost-free conditions! Installation should be performed at Temperatures >10°C. Moreover, the modules must be protected against intensive solar radiation, and temperatures > 50°C!
3. Protect the membrane modules from dust, metal sparks or fines that originate from on-site welding or metal grinding operations as these from of debris will damage the membranes beyond repair.
4. Ensure that the modules are not exposed to mechanical shocks during transportation, unloading or installation. The use of hammers for whatever reason is strictly prohibited.
5. Ensure that modules are not tightened too much during transport and handling to avoid any mechanical stress on the modules components which may end up in damage beyond repair.

5.2 Unpacking of the new IPC® Membrane modules

Keep the modules in their protective plastic packaging as long as possible.

When removing the packaging from the IPC® modules make sure not to damage the membrane envelopes on the top or the bottom of the module. Please inspect the following

- Temp indicator is not triggered (Fig 6)
- Shock sensor is not triggered (Fig 7)
- Inspect the module from the outside to ensure it is not damaged or deformation

Figure 6: Top Cold Mark is OK, Bottom Cold Mark registered frost (you must contact the transport company and your distributor)

Figure 7: Left Shock Watch is intact, middle and right Shock Watch has undergone a Shock (you must contact the transport company and your distributor)

When unpacking the aeration channel please inspect the following

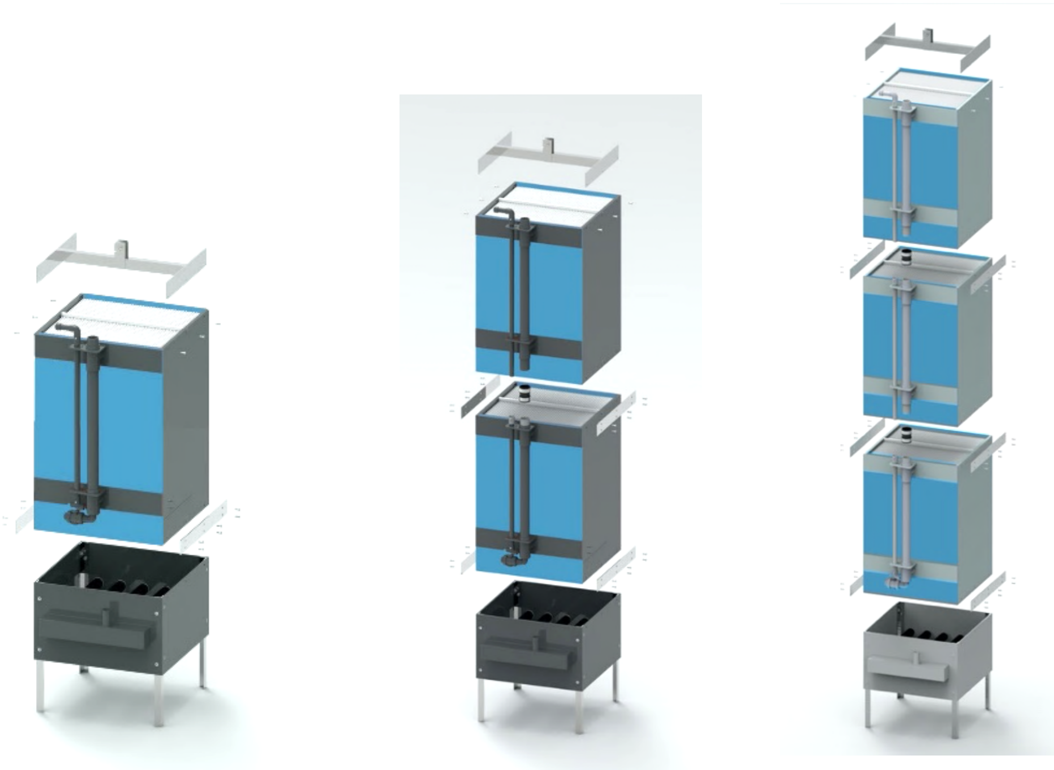
- Are the diffuser tubes fastened and positioned correctly with the blue line facing the top (Fig 8).

Figure 8: Blue line is positioned to the top of the aeration channel.

5.3 Assembly of module towers

Prior to loading the IPC® membrane modules in the tank, they have to be assembled by connecting the aeration channel and the modules as well as build up the module towers to single, double or triple deck module towers (See Figure 9 , further known as “single deck”, “double deck” or “triple deck”).

The assembling has to be carried out on clean, even ground by use of for lifter and / or crane. All safety measures for working with lifted loads have to be respected.



Single Deck Module   Double Deck Module   Triple Deck Module

Figure 9: IPC® Module types

1. In case of a multi-module arrangement the membrane modules will be installed on top of each other and will be screwed on by connection plates (Figure 10, 6). The filtration pipes (5) will be interconnected by hose adapters and hose clamps.
2. The membrane module or the multi-membrane modules will be installed on the aeration channel (7) and will be fixed by 2 connection plates (6).
3. Above the membrane module a lifting device is installed and fixed (Figure 5). The module can be lifted by a crane.
4. The lifting device (3) is equipped with the buoyancy security (1).

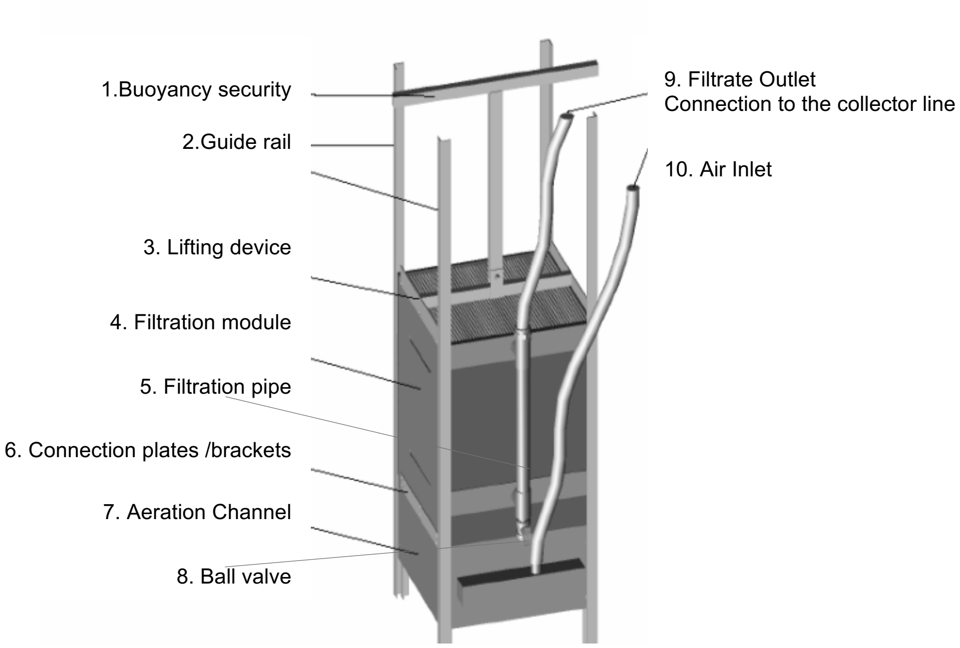


Figure 10: Module and auxiliary parts.

6 Installation of IPC® Membrane modules

6.1 Installation in an empty tank

Follow step 1-4 as mentioned in Section 5.3

5. The aeration hose has to be connected to the aeration channel (Figure 10, 10) - pay attention to the temperature and sewage resistance of the hose. Make sure that the aeration hose is connected to the module stack during module transport and installation to avoid any damage by hanging or loose hose.
6. The mounted tower of modules will be SMOOTHLY lifted from fitting ground and transferred to the filtration tank. Each module tower has to be inserted in the filtration tank by use of the guiding system (2). Make sure that the modules are guided smoothly into the tank and that no mechanical stress weighs on the module towers.
7. The filtration hose adapter (9) will be connected at the top of the filtration pipe (5) of the module tower. The other end of the filtration hose adapter is remaining unbolted to ensure that the air which is entrapped in the module can be released from the module when the tank will be filled with water. The ball valve (8) must be closed and the screwed connection must be tightened.
8. The buoyancy security (1) will be fixed at the tank edge or guiding system in order to avoid a buoying upwards effect of the modules in operation.
9. Connect the aeration hose which is connected to the aeration channel with the air distribution line at the filtration tank.
10. Check/ control the fitting and tightness of all connected hoses and the module interconnection hoses.
11. Ones the module tower is installed in the tank check the tightness of the filtration line applying the following leak test procedure
    A) Close the DN 50 permeate discharge pipe at the top of the tower with pipe stopper (Fig 5).
    B) Supply (dry air and without oil) to the module tower via the pipe stopper connection

       Supply air at 0,3 bar max! Beware not to over pressurise the module as this can damage the membranes
    C) Test with silicon free gas leak spray or soap water the tightness of the different rubber/PVC and mechanical connections
    D) After tightening of the connections, please remove the leak spray by wiping it off. Remove the pipe stopper from the Filtrate connection.
12. Control the tidiness of the tank. All impurities have to be cleaned.
13. Fill the tank with Water (directly after the installation of the modules), in order to allow trapped air to exhaust out of the membrane. The minimum distance between the top of the module and the water surface must not be less than 30 cm after the filling process.

14. Connect the Filtrate line with the module tower and start module commissioning procedure as described in Section 3
15. Should it not be possible to fill the filtration tank with water directly after module installation make sure that modules are protected from dust, sun radiation, high humidity, high temperature and all other influences which may cause damage to the module
16. Should it be necessary to store the modules over longer time in the filled filtration tank without operation make sure that the tank water is kept at a pH between 7,2 and 7,6 and that the water contains 1,0 – 5,0 mg/l free Chlorine.

6.2 Installation in a filled tank

Follow step 1-4 as mentioned in Section 5.3

5. The aeration hose has to be connected to the aeration channel (Figure 10, 10) - pay attention to the temperature and sewage resistance of the hose. Make sure that the aeration hose is connected to the module stack during module transport and installation to avoid any damage by hanging or loose hose.
6. The filtration hose adapter (9) will be connected at the top of the filtration pipe (5) of the module tower. The other end of the filtration hose adapter is remaining unbolted to ensure that the air which is entrapped in the module can be released from the module when the modules will be submerged in the water. The ball valve (8) must be closed and the screwed connection must be tightened.
7. Check/ control the fitting and tightness of all connected hoses and the module interconnection hoses by applying the following leak test procedure

   E) Close the DN 50 permeate discharge pipe at the top of the tower with pipe stopper (Fig 5).
   F) Supply (dry air and without oil) to the module tower via the pipe stopper connection

   Supply air at 0,3 bar max! Beware not to over pressurise the module as this can damage the membranes

   G) Test with silicon free gas leak spray or soap water the tightness of the different rubber/PVC and mechanical connections
   H) After tightening of the connections, please remove the leak spray by wiping it off. Remove the pipe stopper from the Filtrate connection.

8. The mounted and checked module tower will be SMOOTHLY lifted from fitting ground and transferred to the filtration tank. Each module tower has to be inserted in the filtration tank by use of the guiding system (2). Make sure that the modules are guided smoothly into the tank and that no mechanical stress weighs on the module towers. Submerge the modules slowly in the water in order to make sure that entrapped air can be released from the modules via unbolted filtrate connection.
9. After complete submerging of the modules the buoyancy security (1) will be fixed at the tank edge or guiding system in order to avoid a buoying upwards effect of the modules in operation.

The minimum distance between the top of the module and the water surface must not be less than 30 cm after the filling process.

10. Connect the Filtrate hose of the module tower with the filtrate collection line. Connect the aeration hose of the tower with the air distribution line.

11. Check module tower aeration at recommended specific air volume supply. Make sure that all module towers are aerated homogeneously, and air distribution is the same for all module towers.

12. Start module commissioning procedure as described in Section 7.

7 Commissioning

7.1 Step 1: washing out of the glycerine

The membranes are kept in pristine conditions by having Glycerine in the membrane pores. The removal of glycerine may cause excessive foaming for 0,5 days on top of the filtration tank. If the tank is constructed with an overflow, the floating foam will leave the system gradually. If a pump is used to recirculate the sludge in and out of the filtration compartment, the use of a membrane friendly antifoam is highly recommended.

1. Start the filtration cycle at the lowest pumping rate possible and at a high backwash frequency or time.
2. Recommended fluxes are 10-15 LMH brut filtration flux and 20-30 LMH backwash flux.
3. The filtration time / backwash time is in the range of 10 min filtration time and 1 min Backwash time in this step. Monitor the pressure, as it will go down in a matter of 1-4 hours while the glycerine is washed out.

7.2 Step 2: activation of the membrane module

In order to wash all traces of glycerine out of the membrane module prior to use in your installation, the membrane module needs to be treated using hypochlorite.

1. Ensure that there is enough permeate volume in the permeate tank that contains $1m^3$/IPC module that you want to activate the module.
2. Add 2000 ppm of NaOCl to the permeate (or in the permeate tank or added in-line) = 2 Kg pure NaOCl per m^3 . Mostly, NaOCl is supplied in a 12% solution so in this case in 16,7L of NaOCl 12% solution in 1 m^3 of permeate.
3. Backfill at a low flow (possible, 5-10 m3/h) the NaOCl/water solution into the membrane modules in order to replace all the internal water from the modules and to create a 2000 ppm NaOCl concentration in and around the membrane material. Internal volume of the IPC modules (incl 25% safety margin) to be replaced are presented in the table below.

IPC®-25	IPC®-80	IPC®-80 Double Deck	IPC®-80 Triple Deck
30 L	125 L	250 L	375 L

   a. Start the filtration cycle at the lowest pumping rate possible and in backwash mode and replace all the surrounding liquid of the membrane by the NaOCl solution. Rule of thumbs is to pump 2x the internal volume through the membrane in this backwash mode.
   b. Let the membrane modules soak for 3 hours minimum in this solution prior to start-up.

4. After soaking time start the aeration at maximum capacity. Start the filtration device at the lowest pumping rate possible. Suck out the used hypochlorite solution and discharge it in a separate tank if needed.

7.3 Start-up sequence of the membrane unit

- Once wetted, it has to be avoided that the modules are no longer immersed in water or sludge/water mixture with the risk drying out!
- Filtration must never be carried out without sufficient scavenging air (according to the module's data sheet) being blown underneath the modules.

1. Select operational filtration protocol – See "General guidelines for the correct use of IPC® Membrane modules".
2. Start-up at flux 1/3 of the targeted operational flux
   a. Increase flux from 0 tot 1/3 targeted operational flux over a period of 6 hours.
   b. Monitor during 1,5 Day.
   c. Check all operational parameters as mentioned in Section 2 prior to go to the next step.
3. Increase operational flux to 2/3 of the targeted operational flux
   a. Increase flux from 1/3 to 2/3 of the targeted operational Flux for 6 hours
   b. Monitor during 1,5 Day.
   c. Check all operational parameters as mentioned in Section 2 prior to go to the next step.
4. Increase operational flux to 100% of targeted operational flux
   a. Increase flux from 2/3 to 3/3 of the targeted operational Flux for 6 hours
   b. Monitor for 1,5 Day and check all operational parameters as mentioned in Section 2 prior to go conclude a successful start-up.

7.4 Shutdown

7.4.1 Disassembly of the modules

The disassembly of the modules is carried out in the following steps:

1. Shut down the installation

2. Disconnect the aeration unit (depending on the type) at the air inlet (Figure 10, 10).

3. Open the filtration pipe (9), connecting it to the atmosphere.

4. Pull the complete module block (via the buoyancy security, 1) SMOOTHLY out of the tank until the ball valve (8) sticks out of the liquid.

   In case of multi-storied modules pull the block SMOOTHLY out of the tank until the first module sticks out of the liquid. Remove the tube adapter between the top module and the module underneath in order to empty the top module. Repeat this procedure until the ball valve (8) of the last module can be opened.

5. Open ball valve (8) at the bottom membrane module and empty the modules completely.

6. Remove the entire module block out of the tank. Relieve the filtration pipe and the aeration pipe. Pay attention that no person is located in the pivot range of the crane.
7. When putting modules down ensure that they are put on a horizontal level, a clean surface without sharp objects on it. Always put the modules down on the clean full surface and do not tilt.
8. After having removed the connection plates (6), the modules can be separated from each other.
9. You must ensure that the module is not exposed to strong sunlight and / or too high (> +50°C)/ or too low (< +5°C) temperatures or start to dry out.

7.4.2 Rinsing of dismounted modules

The dismounted modules must be rinsed to remove accumulated sludge by means of a SOFT waterjet. Do never use a hard waterjet for the cleaning procedure (e.g. high-pressure cleaner) as the membrane surface could be damaged! The modules should be cleaned until all the accumulated sludge is removed from the membrane surface and from the space between the membrane envelopes. Cleaning is done from top to bottom for the module area which is in contact with the activated sludge.

Prior to, during and after the cleaning, the modules must permanently be kept wet. The modules may never become dry! If the membranes are not used for a longer period, they first need to be **chemically cleaned and conserved before storage**. The chemical cleaning is described in this manual.

7.4.3 Conservation of dismounted modules

The membrane modules must be conserved if they are not used for a longer period in order to avoid any formation of mould. For that purpose, the membrane modules must be properly dismounted and cleaned as presented in this manual.

Modules equipped with IPC® membranes may never become dry. They should either stored immersed in clean water for a short period (a couple of days up to a week), for long term storage the modules should be properly conserved according to the following procedure:

- The modules must be dipped into a solution containing 20 - 40% glycerine and suitable biocide.
- Then, the modules will be drained and are either shrink-wrapped in wet conditions in a plastic bag or will be dried first and then shrink-wrapped in a plastic bag.
- Wet stored modules should NEVER be exposed to frost circumstances.

7.5 Storage of dismounted modules

7.5.1 New modules

New filtration modules have to be stored in dry conditions. During the storage the modules should NOT be exposed to intensive solar irradiation, high temperatures or frost. For storage of the modules in dry conditions, the modules should be shrink-wrapped in plastic bags. The storage temperature should never exceed 50 °C. Please note that the modules are shock sensitive.

7.5.2 Used modules

Already used modules should be cleaned chemically before storage. No cleaning chemicals should remain in the membrane. Storage can be done after adequate conservation of the modules.
The modules can be sent to the manufacturer for reparation and/or regeneration. Before transport, the modules have to be rinsed, cleaned and conserved as described above before shipment. The type of package and the type of shipment have to avoid any damages of the membrane modules caused by transport.

7.5.3 The disposal of old modules

Before being disposed, old used modules have to completely cleaned of sludge. The entire membrane module has to be disposed of as industrial waste.

8 Approved chemicals

The **Blue Foot Membrane N.V.** is recommending the following chemicals:

Application	Chemicals
Conservation	Glycerine
Conservation	Suitable biocide
Cleaning	NaOCl
Cleaning	Ultrasil 73
Cleaning	NaOH
Cleaning	Citric acid

Subsequent you will find notes concerning the conservation chemicals. In case of questions please contact the **Blue Foot Membranes N.V.** and consider the relevant spec sheets.

Glycerine

- Appearance: viscous, colourless liquid
- Density: 1.26 g/cm³ (20°C)
- pH value: 5 (100 g/l H_2O. 20°C)

Ultrasil 73

Ultrasil 73 is used as a cleaning product to preserve the membranes against mildew and algae formation.

- Appearance: yellow-brown liquid
- Density: 1.05 g/cm³ - 1.09 g/cm³
- pH-value: 2.1 - 2.7

- Direct contact of skin and eyes with Ultrasil 73 has to be avoided!
- Breathing in or swallowing of Ultrasil 73 has to be avoided!
- While handling with Ultrasil 73 goggles and protective glove must be worn!
- Do never pump an already extracted portion back to the reservoir!
- Please note the safety data sheet!

8.1 Manufacturer's declaration

Declaration for the installation of an incomplete machinery
in terms of the Machinery Directive 98/37/EG, Annex II B

Herewith we,
Blue Foot Membrane N.V.
Gerard Mercatorstraat 31
B-3920 Lommel, Belgium

declare that the commissioning of the subsequently named incomplete machinery is prohibited until it was noted that the machinery in which the incomplete machinery will be installed in, is corresponding to the EG-machinery directive.
We approve the conformity to the Low Voltage Directive 2006/95/EWG.

Product:	Ultrafiltration-Membrane module Type	IPC® 7-001
		IPC® 25-002
		IPC® 80-002

Engineer standards:	98/37/EWG
	EN 292-1
	EN 292-2

The special technical documents for incomplete machinery according to the Machinery Directive 98/37/EG, Annex VI, are present.

8.2 List of substances damaging the membrane

Substances	Effect on membrane	Concentration	
1,1,1-trichlorethane		1	g/l
1-Nitropropane		2	g/l
2 N NaOH			
3 N KOH			
5 % ClOH		50	g/l
Acetone	solvent	2	g/l
Amyl-alcohol		20	g/l
Fuel	solvent	2	g/l
Benzene	solvent	1	g/l
Butadiene	solvent	2	g/l
Butyl-alcohol/butanol		1	g/l
Cationic polymers			
Cresol	solvent	1	g/l
Cyclohexane	solvent	1	g/l
Diacetone alcohol	solvent	2	g/l
Dichlorethane	solvent	1	g/l
Dimethyl formamide	solvent	1	g/l
Diesel oil	closing the pores	2	g/l
Dimethyl sulfoxide	solvent	1	g/l
Iron - & manganese sludge	closing the pores	2	g/l
Ethyl alcohol / ethanol	solvent	200	g/l
Ethylene chloride	solvent	1	g/l
Ethyl formate	solvent	2	g/l
Formaldehyde		50	g/l
Soak wax	irreversible closing of the pores	2	g/l
Isopropyl alcohol	solvent	100	g/l
Cationic tenside		2	g/l
Cationic polymers			
Base pH > 12	precipitations		
Methyl alcohol / methanol	solvent	50	g/l

Substances	Effect on membrane	Concentration	
Methylene chloride	solvent	1	g/l
Methyethylketone	solvent	2	g/l
Methylisobutylketone	solvent	2	g/l
Non emulsified organic fats	closing the pores	2	g/l
Nitrobenzene	solvent	1	g/l
Nitro dilution	solvent	2	g/l
n-methyl Pyrrolidon	solvent	1	g/l
Phenol	solvent	1	g/l
Piperidine	solvent	1	g/l
Pyridine	solvent	1	g/l
Acid pH < 2			
Silicone oil	irreversible closing of the pores	2	g/l
Carbon tetrachloride	solvent	1	g/l
Tetrahydrofuran	solvent	1	g/l
Toluole	solvent	1	g/l
Toluen	solvent	1	g/l
Trichloroethylene	solvent	1	g/l
Xylene	solvent	1	g/l
Xylol	solvent	1	g/l
Sharp-edged solids	damage of the membrane		
Degreaser	soaking/power drop	1	g/l

9 Follow-up during normal operation

9.1 Process measuring and control technology

Adequate process measuring and control are crucial while operating an MBR. To guarantee a safe and stable process the following process parameters should be measured online:

- Transmembrane pressure during filtration and during backwash per membrane module or membrane module tower.
- Membrane permeability as well as temperature of the feed.
- Filtration Cycle including Air flow rate for the aeration of the membrane.
- MLSS-concentration of the sludge.
- Dissolved oxygen in the activated sludge tank.

REGULAR TESTS	
Frequency	**Checklist**
daily	- Visual check of permeate regarding suspended matter - Visual check regarding leakages - Visual check of bubble's arrangement on water surface - Detailed analysis of influent, and seed sludge (PH, Temperature, Conductivity, SS, MLSS, BOD, COD, TKN, NH4-N, NOX-N, Cl- , FOGs, PO4-P, TP, Total calcium and magnesium hardness) - Checking and recording the operational parameters - permeability - MLSS-concentration - flowrate - transmembrane pressure - amount of scouring air - Optional are MBR treatment quality tests like Sludge Filterability Test, Time to filter (TTF), Solids Volume index (SVI)
monthly	- Checking amount of stocked spare parts

9.2 Service and cleaning procedures

Regular maintained IPC®-membranes will have longer lifecycles. Besides daily visual checks the maintenance work includes replacement of wear and tear parts.

Frequency	Maintenance Required
Daily	None, except sludge removal as required
Weekly	1. Routine sampling of MLSS (or as required).
Weekly /Monthly as required	Chemical Maintenance clean
Fortnightly / Monthly	1. Visual inspection of final effluent 2. Visual inspection of M&E equipment 3. Check on Screenings collection 4. Check on Sludge / MLSS production
Six-Monthly	Chemical Recovery cleaning of membrane units.
Annually	Drain tank to reveal membrane unit manifolds (upper unit), water hose clean and visually inspect membrane unit manifolds
Every five years	1. Remove and inspect membrane unit panels for signs of wear and excessive fouling. 2. Undertake cleaning and replacement as necessary.

- Check- and maintenance frequency should be followed according to the manual.
- In case of service teams with several persons, the responsibilities should be clearly appointed.
- Do not repair damaged/ broken pipes but replace these. Do exchange hoses directly if porosity or tear is visible.
- Do retighten leaky screwing only in depressurized condition. Hose connections between different installation parts and engines should be intact and protected against damage.
- Do only use acceptable and compatible tools. Damaged parts should be exchanged in time.

9.3 Replacing the aeration elements

The tube diffusers located in the aeration module underneath the membrane modules, are subject to wear and must be checked and replaced from time to time. Filtration without proper and sufficient aeration may lead to irreversible damage to the membrane modules.

The aeration cartridges in the aeration module are to be checked for performance regularly (even bubble distribution over the entire length of the cartridge) and replaced if necessary to ensure proper aeration. A visual check of the aeration at regular intervals by lifting out the aeration unit is also recommended. The life of the aeration cartridges may vary greatly depending on the wastewater.
Replacement is to be performed regularly:

- Municipal wastewater: every 2-5 years (depending on condition)
- Industrial wastewater: every 1-3 years (depending on condition)
- The old aeration devices are first removed and the condition of the ¾" connection is checked. If necessary, the connection must also be replaced.
- The connections are cleaned and re-sealed with Teflon tape.
- The location of the perforations in the rubber is particularly important when screwing in the aerator. The perforations must be located at the left and right at the side of the tube diffuser seen from above (and thus not located on top and bottom of the diffuser) to allow formation of an even bubble carpet underneath the module. Some aerators have a blue strip alongside the aerator rubber material. This strip has to be oriented to the highest point of the tube

> - Ensure, when fitting the diffuser tubes, that the perforations are positioned correctly to the module (left and right side of diffuser tube).
> - Defective diffusers lead to blockage of the membrane modules and may damage the modules! Always ensure that filtration only takes place with functioning aeration.

9.4 Monitoring

During the monitoring process the following parameters should be controlled and recorded in order to guarantee a reliable operation process and a high-class permeate quality. One example is presented in Table 7.

Table 7: Form for monitoring procedure

		Mon	Tue	Wed	Thu	Fri	Sat	Sun
Name								
Date								
Time								
Operation hours	**[h]**							
Time since cleaning	**[h]**							
Time since back wash	**[h]**							
Operation rate	**[min]**							
Pause rate	**[min]**							
Pressure operat. rate	**[mbar]**							
Pressure pause rate	**[mbar]**							
Permeability	**[l/(m²hbar)]**							

Flux	**[l/(m²*h)]**							
max. Flux in 24h	**[l/(m²h)]**							
for x hours	**[h]**							
min. Flux in 24h	**[l/(m²h)]**							
for y hours	**[h]**							
Permeate flow rate	**[l/h, m³/h]**							
Permeate appearance								
N_{total} of permeate	**[mg/l]**							
NH4-N of permeate	**[mg/l]**							
COD of permeate	**[mg/l]**							
BOD_5 of permeate	**[mg/l]**							
P_{total} of permeate	**[mg/l]**							
Temperature	**[°C]**							
MLSS-concentration in filtration tank	**[kg/m³]**							
pH-value in filtration tank	**[-]**							
Conductivity in filtration tank	**[µS/cm)**							
Sludge volume	**[ml/, %l]**							

10 Annex 1

10.1 MBR Nomenclature

Listed below is a short overview of critical definitions concerning membrane bioreactors and membrane technology. Synonyms are mentioned within brackets.

Backwash

Short term reversal of the flow direction through the membrane (using permeate) in intervals to remove the particles that accumulated on and in the membrane during the filtration process (Backpulse / Backflush).

Biofouling

Development of biofilm on the membrane surface or in the membrane due to growth of micro-organisms. Potential fouling mechanism in MBR applications.

Cake layer

Deposit on the membrane surface caused by the filtration process comprising retained organic and inorganic substances. Major resistance factor for flow through the membrane in MBR applications.

CAS

Classical activated sludge system

CIP treatment

Clean-in-Place is a chemical cleaning procedure where the IPC® module is cleaned without being removed from the membrane tank.

Clogging

Accumulation of solids within the membrane module or system.

Concentrate

Portion of the flowrate which will be retained by the membrane. In the case of MBR activated sludge will be retained.

Cross flow

Traverse flow induced by liquid flow (pumped or by air scour) which develops at the membrane surface and serves to control the cake layer.

NOTE: As result of the two-phase flow, the effective mechanisms clearly differ from the principle of classic crossflow operation of pressure tube systems with inside flow.

Cycle

Temporal sum of the filtration phase, backwashing phase and/or relaxation phase (cyclic operation, filtration cycle).

Feed flow

Flowrate charging the membrane bioreactor system at the inlet of the biological aeration tank, e.g. activated sludge, expressed in m^3/day.

Filtrate

Water separated from the feed by pore filtration (mixture of substances).

Flux, corrected

Flux which is corrected for feed water temperature. This flux is recalculated to flux at 20°C (J_{20}) and *expressed in l/(m².h)* (normalised flux).

NOTE: The water temperature has a major impact on the maximum allowable flux, due to the fact that the transmembrane pressure is proportional to the water viscosity.

$J = J_{20}\, 1{,}025^{(T-20)}$

Where T is feed water temperature (°C).

Alternatively, the following calculation can be used;

$$J_{T_0} = J\left[\frac{42.5+T_0}{42.5+T}\right]^{1.5}$$

where

J	:	Flux observed (LMH or gfd)
JT_0	:	Flux at reference temperature (LMH or gfd)
T	:	Water temperature (°C)
T_0	:	Reference temperature (°C)

Flux, critical

Flux below which the permeability decline is considered negligible. During operation of the membrane below a certain flux („subcritical“) there is limited decrease of the membrane performance observed. However, while exceeding this critical flux („overcritical“),a reinforced membrane fouling and a rapid performance decrease of the membrane is noticed.

Flux, net

Flux during the filtration cycle, expressed in l/(m².h). This flux type is considering filtration breaks, back-flow periods and the volume of filtrate needed for the backwash process.

Flux, operational

Actual flux during the filtration expressed in l/(m².h) (instantaneous flux, gross flux or brut flux).

Flux, specific

The flow rate of a membrane is an indicator of the capacity under certain circumstances. If the flow rate is related to the membrane surface, the result is the specific flux l/(m².h) of the membrane.

Flux, sustainable

Flux for which the transmembrane pressure increases gradually at an acceptable rate such that recovery cleanings are not necessary.

Fouling

Deposition of existing suspended and dissolved material from the feed stream, on the membrane surface, at or in pores of the membrane structure. Depending on the materials provoking the fouling it is differentiated between colloidal fouling, inorganic fouling (scaling) organic fouling and biofouling. Fouling can be reversible or irreversible. Fouling always results in a reduction of the performance or the permeability of the membrane;

Maintenance cleaning

Cleaning with chemicals to maintain the membrane permeability. This regular cleaning is executed during normal operation and uses less aggressive procedures and/or chemicals than recovery cleaning.

Membrane

Selective barrier which causes the retention of the mixed liquor particles in the membrane bioreactor.

Membrane area

Membrane surface, which is available for the filtration process, expressed in m^2.

Membrane module

Component, which is ready for connection (functional) and which consists of the membrane or the membrane element, collecting line and fittings.

MLSS

Mixed liquor suspended solids is the concentration of suspended solids originating from the microbial culture for biological degradation in activated sludge/MBR operations. MLSS is expressed in mg/l or g/l.

Operational pressure

The operational pressure is the driving force for the physical separation process with porous membranes and is necessary in order to guarantee a filtration process. The operational pressure is consisting of the transmembrane pressure (TMP) and several pressure losses occurring in the connected periphery of the system, is expressed in kPa or mbar.

Permeability

Parameter for the description of the hydraulic performance of a membrane, which is the quotient of the gross permeate flux and the transmembrane pressure. Permeability is expressed in $l/(m^2.h.bar)$.

Permeability, clean water

The hydraulic performance of a membrane operating in clean water, is expressed in $l/(m^2.h.bar)$.

Permeability, corrected

Permeability corrected for the effect of temperature on viscosity, is expressed in $l/(m^2.h.bar)$.

Permeability, normalized

Permeability which is corrected for a reference temperature in order to allow a more accurate comparison of the values, is expressed in $l/(m^2.h.bar)$.

Permeate:

Portion of the feed stream that passes through the membrane.

Pore size

Average pore size of a porous membrane, relevant for the retaining performance of a membrane. The pores of a membrane will usually not be homogenous – they will be characterized by a particle size distribution, expressed I µm.

Recovery Clean

Intensive cleaning with chemicals to recover the membrane permeability

Relaxation

Ceasing permeation whilst continuing to scour the membranes with air bubbles.

Retentate

Portion of the feed stream which is retained by the membrane (e.g. activated sludge)

Scaling

Precipitation of inorganic solids on the membrane surface, if concentration exceeds the solubility limits.

TSS

Total suspended solids (mg/l)

Transmembrane pressure (TMP)

The driving force of the separation process is the pressure difference between feed-side and permeate-side. The pressure loss is caused by resistance of the membrane layer + cake layer + fouling layers. TMP is expressed in kPa or mbar. In case of the submerged low-pressure-filtration the transmembrane pressure is created by a negative pressure on the filtrate side. Correct calculation of the TMP is presented in section 10.3.

Viscosity

Property of a fluid to resist to internal movements (turbulence) or global movements (flow). Viscosity is expressed on Pa.s.

Note: the water viscosity, which is strongly dependent on temperature, given in the following formula:

$V_t / V_{20} = 0{,}3804 + 0{,}6196 * EXP\ (0{,}0404 * (20-t))$

Where V_t : Water viscosity at t °C

and V_{20} : Water viscosity at 20°C

10.2 Parameters for characterisation of the wastewater

Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand is a sum parameter for determining the organic pollution rate of the wastewater. The necessary oxygen demand for bio-chemical metabolism processes of easily degradable solids is appointed on standardized basic conditions. E.g. the BOD_5 is determining the volume of the oxygen necessary for the biological degradation of the solids comprised in the wastewater at a temperature of 20°C during 5 days. The higher the BOD-value, the higher is the biodegradable portion of the raw water. BOD is expressed in mg/l.

Chemical Oxygen Demand (COD)

The chemical oxygen demand test is commonly used to indirectly measure the amount of organic compounds in water. Contrary to the BOD-parameter the COD is detecting the biotic degradable as well as the non-biotic degradable substances. Volatile compounds which easily evaporate cannot be registered. The higher the COD-value, the higher is the portion of the organic and the inorganic compounds in the raw water. COD is expressed in mg/l.

Total Organic Carbon (TOC)

The TOC is the amount of total carbon bound in an organic compound. The dissolved organic and the individual organic bound carbon are registered. Compared to the COD-parameter the bond rate, the oxidation rate and the physical condition are not considered. The procedure of the TOC-determination is a burning process in which all the carbon compound, part of the assay, will be oxidized to CO_2. TOC is expressed in mg/l.

pH-value

The pH-value is considering the concentration of hydrogen-ions and is so an indicator of acidity in aqueous solution. The pH-value is the negative common logarithm of the hydrogen-ion-concentration which is calculated as mol H+/L. The smaller the pH-value, the higher is the acidity of the solution. The pH-value of the activated-sludge-water-mix has to be between 6.5 and 8.5, otherwise the metabolisms of the biomass will be interrupted. For a detailed analysis of the available acid-/ base volume in addition the acid capacity resp. the base capacity has to be determined.

Acid capacity / base capacity

The result of the acid capacity is an indicator for the buffer capacity of the water compared to acid and is so guaranteeing the pH-value-stability. The acid capacity of the water indicates the volume of acid – in practice 0.1 mol/L hydrochloric acid - which is dissipated until achieving a pH value of 4.3. Caustic soda is used for the base capacity in order to reach a pH value of 8.2 for a defined amount of water.

Temperature

While operating a biological wastewater treatment installation it has to be paid attention to the temperature as it strongly affects the metabolism of the micro-organisms. Extreme (too low or too high) temperatures may negatively harm the biological degradation process and may even destroy the biomass in the reactor. The optimized temperature for a biological wastewater treatment is set between 10°C and 30°C.

Conductivity

In wastewater is the conductivity a sum parameter for the concentration of ions and the salt compounds. The results are stated based on a reference temperature (usually 25°C); 0.1 mS/m at 25°C corresponds to 0.425 mg/L salt content (mg/L TDS = total dissolved solids). The higher the electrical conductivity, the higher is the rate of the dissolved salts. The measurement of the conductivity serves amongst others for monitoring the salt-concentration of the influent. The conductivity is measured in S/cm.

Nutrient rate

In order to guarantee a successful biological degradation, the rate of BOD_5 to nitrogen to phosphorus should be approx. 100:5:1 (DWA, 1997[1]). A lack of one of these nutrients may harm the biological degradation process.

Total suspended solids

Portion of the total solids that is retained on a filter with a specific pore size (1,58 um for Watman glass fiber filter), measured after being dried at 105°C (TSS in mg/l)

Total dissolved solids

The solids that pass though the filter, the water is evaporated and dried. TDs comprises of colloidal and dissolved solids (TDS in mg/l)

Total Kjeldahl Nitrogen

Total of organic and ammonia Nitrogen (TKN in mg/l)

[1] DWA (1997): Biologische und weitergehende Abwasserreinigung. Ernst & Sohn Verlag, 4. Auflage

NH_4-N

Nitrogen present in the form of Ammonia (in g/m^3) in oxidation state (-III). Depending of the pH this N is present as ammonium or ammonia gas (expressed in mg/l).

NO_3-N Nitrogen present in the form of Nitrate in g/m^3 in the highest oxidation rate (V) (in mg/l).

Total Phosphourous

The total amount of P present in the wastewater. The usual form of phosphor in natural water and wastewater bodies are phosphates. The forms of Orthophosphates PO_4 are available and essential for biological metabolism (in mg/l).

Alkalinity

Alkalinity in wastewater results from the presence of hydroxides, carbonates and bicarbonates. The alkalinity in wastewater helps to resist changes in the pH caused by the addition of acids, wastewater is normally alkaline. Concentration of alkalinity is important for biological treatment, and BNR. Is expressed in terms of $CaCO_3$ in mg/l or in meq/l.

10.3 Calculation of Transmembrane Pressure

Pressure transmitter to direct the permeate pump is used for:
Measurement of the permeate pressure (P_p)
Calculation of the Transmembrane pressure (TMP)
The permeate pressure will be measured, and the TMP will be calculated as follows:

TMP (mbar) = $-P_p$ (mbar) + P_H (mbar)

The TMP is defined positive in production mode, when the permeate pump sucks water though the membrane to produce permeate. The measured pressure will be negative, because in this situation the pressure transmitter is on the suction side of the pump.

The TMP is defined negative in back-flush mode, when the permeate pump presses water through the membrane to clean its surface on the outside. The measured pressure will be positive, because in this situation the pressure transmitter is on the pressure side of the pump.

The hydrostatic pressure P_H on the pressure transmitter results from the liquid level in the Membrane Tank and must be added to the TMP. Assuming the density of water – 1,0 Kg/l, and gravity – 10 m/s^2, P_H is approximately:

P_H (mbar) = L (cm) – H (cm)

Here, L is the liquid level of the Membrane Tank and H is the vertical mounting position of the pressure transmitter, both measured from the ground level. This is demonstrated in the figure below. L and H values to be determined during start-up.