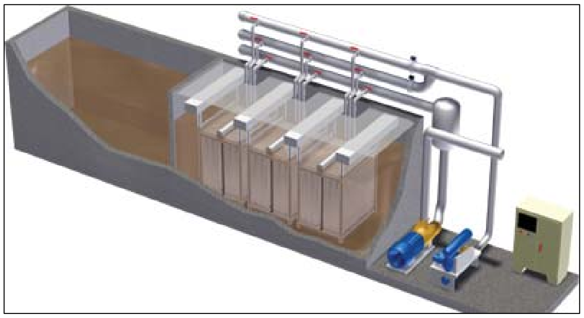
CIE4485
Wastewater Treatment

Maria Lousada Ferreira

4. Membrane BioReactors

Membrane BioReactors



Maria Lousada Ferreira

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1-Introduction
1.1 Background

"Water scarcity affects one in three people on very continent of the world" [WHO, 2009]

Water exploitation index (percentage) [EC, 2010]

Water exploitation index-WEI

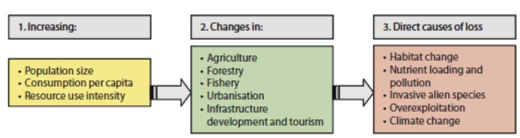
Amount of water used compared with the available long term fresh water resources.

>=20% water scarcity

>40% severe problem

1-Introduction
1.1 Background

Widespread concern about biodiversity loss



Causes of biodiversity loss [EC, 2010]

Nature 2000- network of natural habitat and species sites-aimed at preserving biodiversity.

The Netherlands 10 % of the territory are Nature 2000 sites [PBL 2003].

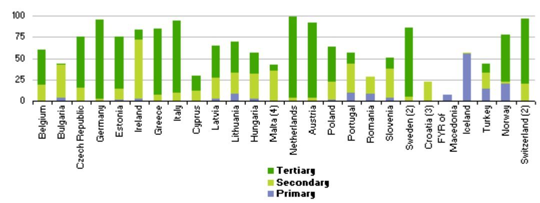
Protected areas: mainly major water bodies (surface area of inland waters and the North Sea, in a total of about 2900 km^2)

⇒ wetlands have to achieve good ecological status by 2015 (WFD)

1-Introduction
1.1 Background

Water cycle should be optimal !!

All wastewater should undergo a certain level of treatment.



In certain locations

⇩

Advanced treatment

Followed by reuse

(1) Hungary, the Netherlands, Austria, Sweden and Turkey, 2006; Ireland, Italy, Cyprus, Romania (only tertiary treatment), Iceland and Switzerland, 2005; Denmark, Spain, France, Luxembourg, Slovakia, Finland and the United Kingdom, not available.
(2) Primary, not available.
(3) Primary and tertiary, not available.
(4) Malta 2008
Source: Eurostat (env_watq4)

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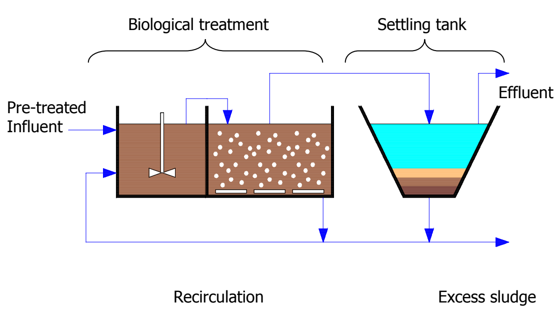
1- Introduction
1.2 Membrane bioreactors

Conventional activated sludge system: activated sludge separated from treated water (effluent) by sedimentation in secondary clarifier (settling tank).



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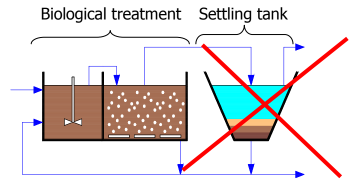
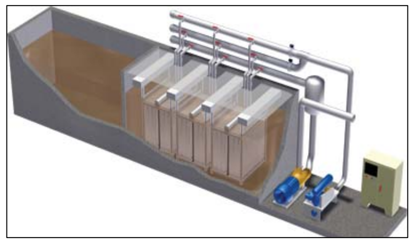
1-Introduction
1.2 Membrane bioreactors (MBRs)



MBRs are a compact wastewater treatment system in which sludge and clear water are separated by membrane filtration

MBRs produce a high quality and largely disinfected effluent, therefore especially suitable for reuse purposes or for discharging in environmentally sensitive water bodies.



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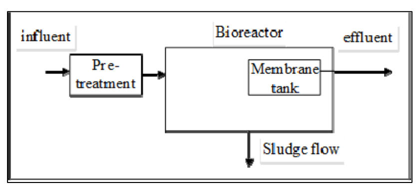
1-Introduction
1.2 Membrane bioreactors

Pre-treatment: sieves to remove coarse and fine materials.

Bioreactor: removal of carbonaceous material and, if properly designed, phosphorus and nitrogen.

Membranes: usually submerged in the activated sludge of the bioreactor.

Effluent (permeate): no suspended solids and largely desinfected.



Schilde MBR, Belgium

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1-Introduction
1.2 Membrane bioreactors

Parameter	Removal efficiency (%)	Permeate quality	wwtp effluent
TSS, mg/L	>99	n.d.	5-8
Turbidity, NTU	98.8-100	<.5	
COD, mg/L	89-98	10-30	30-70
BOD, mg/L	>97	<5	4-15
NH_3-N, mg/L	80 – 90	<5-6	5-12
N_{TOT}, mg/L	36 – 80	<10	
P_{TOT}, mg/l	62-97	0.3 – 3	1-3
Total coliforms, CFU/100 m	5 – 8 log	<100	
Faecal coliforms, CFU/100 mL	-	<20	
Bacteriophages, PFU/100 mL	>3.8 log	-	

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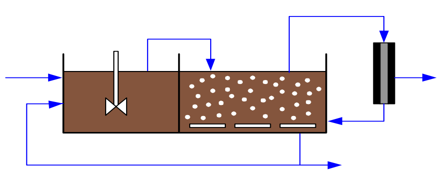
2- MBR technology background

MBR process:
•introduced late 1960s
•Invented by Dorr-Oliver Inc
•Application for ship-board sewage treatment
•Activated sludge bioreactor with a cross-flow membrane filtration loop



MBR process configuration : side-stream

Early MBR systems:
-Expensive (due to membranes and fouling)
-High energy consumption (10 kWh/m^3 produced permeate)

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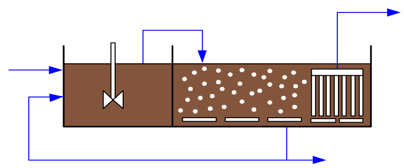
2- MBR technology background

•In 1989 Yamamoto presented a new MBR design with submerged membranes;
•Membranes submerged in activated sludge tanks where the static pressure contributed for the extraction of permeate.



MBR process configuration : submerged

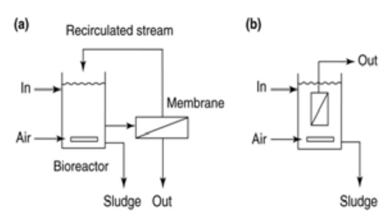
New MBR systems:
-Modest fluxes were applied (25% less than earlier systems);
-Air was used to control fouling;
-New MBR design, and decreasing membrane costs, stimulated MBR applications, since mid 1990s.

2- MBR technology background

	Early MBRs	New MBRs
SRT	100 d	20 d
MLSS	30 g/L	8-15 g/L

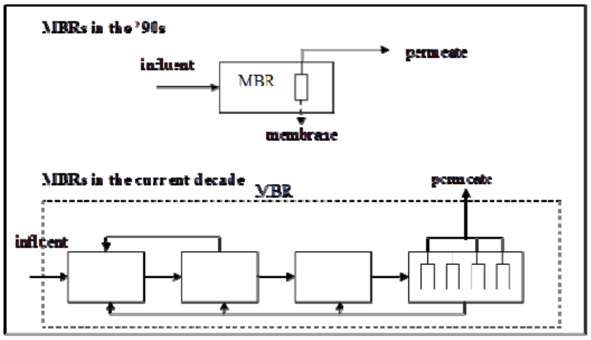
New MBRs
•Fouling decreased;
•Membrane cleaning simplified;
•Energy consumption ± 1 kWh/m^3 produced permeate.

Commercial options



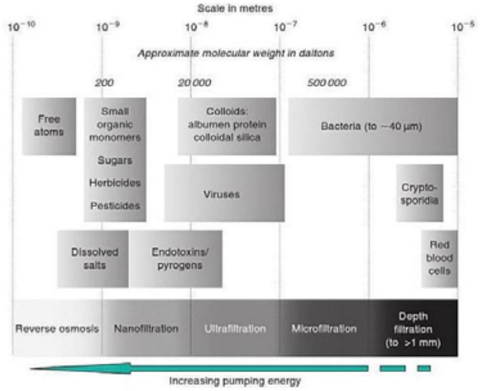
MBR process configurations (a) side-stream (b) submerged [Judd, 2008]

2- MBR technology background



Layout of the MBR process during the 1990s and the current decade [Lousada-Ferreira, 2011].

3- Membrane technology



Components removed by each pressure-driven membrane operation [Judd, 2006]

Membrane operations

- Reverse osmosis- separation by different solubility and diffusion rates of water and solutes in water;
- Nanofiltration- separation through combination of charge rejection, solubility-diffusion and sieving through micropores;
- Ultrafiltration- separation by sieving through mesopores;
- Microfiltration- separation of suspended solids from water through macropores.

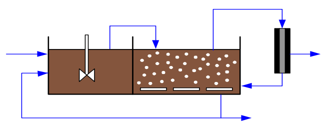
4- Process configuration

Membrane process configuration

- •Extractive MBRs- membrane used to extract specific components from the bioreactor;
- •Diffusive MBRs- membrane used to introduce gas into the bioreactor;
- •Rejection MBRs- Biomass is retained in the bioreactor while clarified water goes through the membrane.

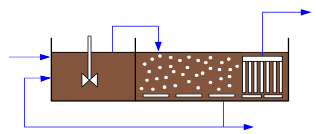
Rejection MBRs

Biological treatment + membranes (inside or outside the bioreactor)



Side-stream MBRs

- •Higher fluxes; greater hydrodynamic control
- •Lower permeability



Submerged MBRs

- •Lower fluxes;
- •Higher permeability

4 – Process configuration

Membrane configuration

Hollow fiber (HF)

Submerged applications

Cheaper than FS

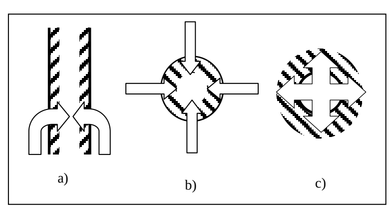
More cleaning than FS

Multi-tubular

Side-stream applications

Flat sheet (FS)

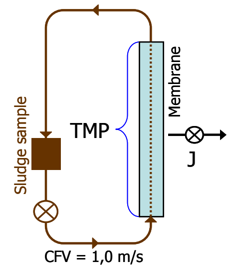
Submerged applications



Schematic flows through FS (a), HF (b) and tube (c)

4 – Process configuration

- Membranes mounted in modules;
- Modules composed of: membranes, support structures, inlets and outlets.
- Pumps, placed in the clean water side of the membranes, draw the water through the membrane while solids are retained in the bioreactor.
- Compressed air is introduced, by a distribution manifold at the base of the modules, to:
  - keep the biomass in suspension;
  - continuously scour the membrane;
  - provide dissolved oxygen to biomass (if necessary in membrane tanks).



Scheme of the Delft Filtration Characterization Installation (DFCi)

MBRs work in cross-flow filtration mode, i.e. for a single passage of activated sludge across the membrane only a fraction is converted into permeate.

5- Relevant operational parameters

- Trans-membrane pressure (TMP)

  $TMP = \Delta P = P_{feed} - P_{permeate}$

- Flux (J)

  $$J = \frac{TMP}{\mu R_t}$$

  ΔP- [Pa or bar]
  μ - permeate dynamic viscosity [Pa.s]
  R_t - total filtration resistance [m^{-1}]
  J- [$L/m^2.h$]

- Total resistance (R_t)

  $R_t = R_m + R_f$
  R_m- clean membrane resistance [m^{-1}]
  R_f- fouling resistance

- Permeability (P)

  P= J/TMP

5- Relevant operational parameters

- MBRs work with constant flux.

General operating conditions for submerged MBR:

- Transmembrane pressure → ± 20 kPa
- Flux sustainable long-term → 15 – 30 L/m²*h
- Solids retention time → > 20 days
- Hydraulic retention time → 1 – 9 hours
- Food to mass ratio → < 0.2 kg COD/ (kg MLSS·day)
- Sludge production → < 0.25 kg SS/ (kg COD·day)

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6 – Advantages vs. disadvantages of MBR technology

Advantages of MBR technology

- High quality and largely disinfected effluent (permeate)
- Smaller footprint
- Operation at high MLSS concentration (usually between 8 and 15 g/L)
- Higher volumetric loading rates =>shorter HRT
- Longer SRT => less sludge production
- Operation at low DO with potential for simultaneous nitrification-denitrification, in long SRT designs
- Independent control of SRT and HRT

Disadvantages of MBR technology

- High capital costs (membranes)
- Potential high cost of membrane replacement (limited data on membrane life time)
- High energy costs
- Need to control membrane fouling
  - Fouling: process leading to deterioration of flux due to surface or internal blockage of the membrane

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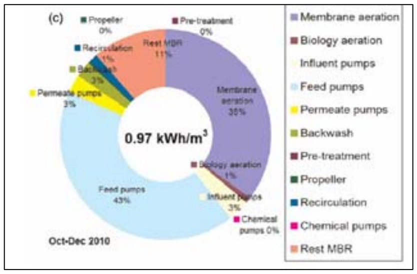
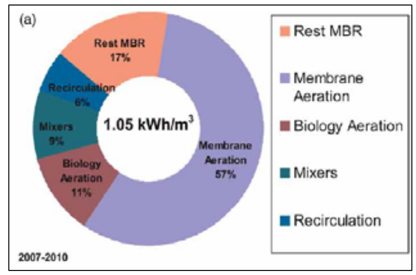
6 – Advantages vs. disadvantages of MBR technology





Energy consumption at MBR Terneuzen (c) and MBR Heenvliet (a).
(Krzeminski et al. (2012))

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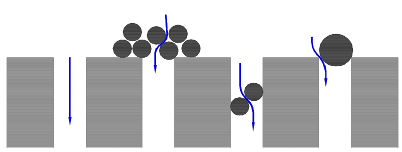
7- Fouling

Fouling: Process dealing to detereoration of the flux due to surface or internal blockage of the membranes (Judd, 2006)

Clogging: blockage of the channels between the membranes and/or aerator ports (Judd, 2008)



Schematics of the fouling mechanims: cake filtration (B), adsorption (C1), pore blocking (C2).

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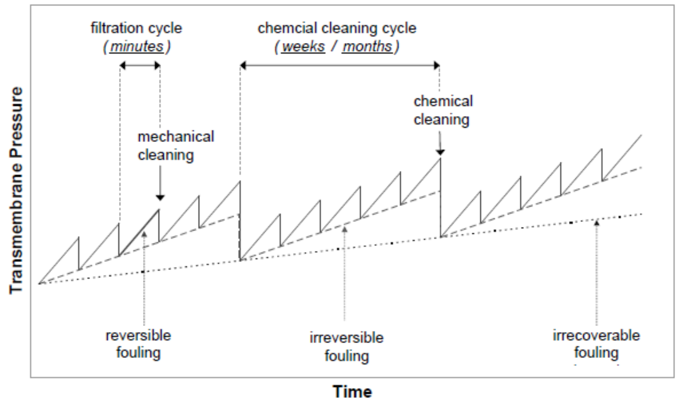
7- Fouling

Fouling during constant flux operation [Kraume, 2009].



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6- Fouling

<u>How to minimize fouling:</u>

•Operate at high shear (more air; more cross-flow velocity…);

•Operate at low flux.

<u>How to remove fouling:</u>

•Physical cleaning: membrane relaxation;

•Chemical cleaning: enhanced backwash, maintenance cleaning or intensive cleaning.

<u>How to limitate fouling:</u>

•Optimizing membrane properties and operating conditions;

•Adding sludge coagulants/flocculents or adsorbent agents.

•(…)

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7- Fouling

- Extracellular Polymeric Substances (EPS)
  - Macromolecules: polysaccharides, proteins, nucleic acids, lipids, etc
  - Function: Substances that bound the particles together
- Soluble microbial products (SMP)
  - Soluble part of EPS, that is, materials that are not integrated in biological flocs
- Dissolved organic matter
- Submicron particles

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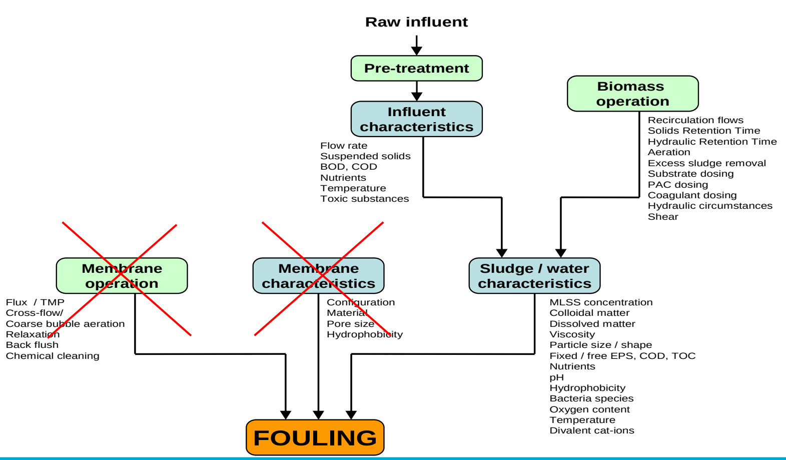
7- Fouling



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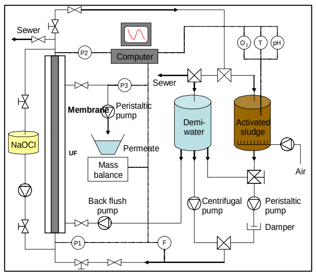
7.1 The Delft Filtration Characterization method

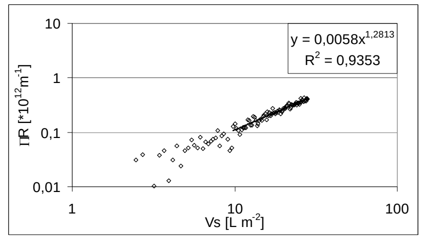
The Delft Filtration Characterization method (DFCm) (Evenblij, 2005) comprises:

1. Measurement of membrane resistance
2. Measurement of sludge filterability
3. Cleaning of the membrane



The Delft Filtration Characterization Installation (DFCi)

- Single Tube UF (X-Flow); nominal pore size0.03 µm
- Constant operation: J= 80 L/m².h; V= 1 m/s



Example of DFCi output

ΔR_{20} values and corresponding sludge filterability

	Filterability
$\Delta R_{20}< 0.1$	Good
$0.1<\Delta R_{20}<1$	Moderate
$\Delta R_{20}>1$	Poor

[Geilvoet, 2010]

H. Evenblij, S.Geilvoet, J.H.J.M. van der Graaf and H.F. van der Roest (2005) Filtration characterization for assessing MBR performance: three cases compared, Desalination (178) 115-124.

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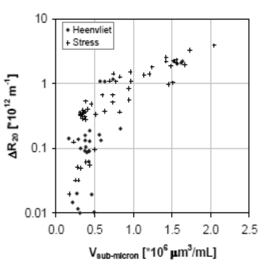
7.1 The Delft Filtration Characterization method

Filterability-The fouling potential of the sludge, as measured by the Delft Filtration Characterization method (DFCm) [Evenblij, 2006]



	Filterability
$\Delta R_{20}< 0.1$	Good
$0.1<\Delta R_{20}<1$	Moderate
$\Delta R_{20}>1$	Poor

The volume of sub-micron particles is likely to be a better indicator of sludge filterability than EPS/SMP [Geilvoet, 2010].

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8- MBR Technology questions and challenges

- Design and operation:
  - Is a separate membrane tank needed?
  - Which are the optimal operational parameters, such as MLSS concentration or flux?
  - How to further reduce energy comsumption in MBRs?

Nordkanal MBR, Germany

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8- MBR technology questions and challenges

Low MLSS concentration	High MLSS concentration
Design	
Separate membrane tank not required	Separate membrane tank preferable
Operation	
Less clogging	More clogging
Less air required to scour the membrane and provide DO to the biomass	More air required to scour the membrane and provide DO to the biomass
Less air preferable to promote floc growth	Less air preferable to promote floc growth=> Air flow requires optimization
Applied return ratio is irrelevant	Low return ratio, i.e. lower than 2, preferable to achieve improved filterability

Lousada-Ferreira, M. (2011). Filterability and sludge concentration in Membrane Bioreactors Water Management Department. Delft, Delft University of Technology. ***PhD:*** *222.*

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Questions?

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