POLITECNICO DI MILANO

UNIVERSITÀ DEGLI STUDI DI PALERMO

Palermo, May 11th 2015

Membrane bioreactors - MBRs

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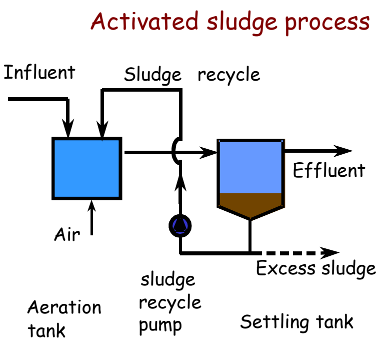
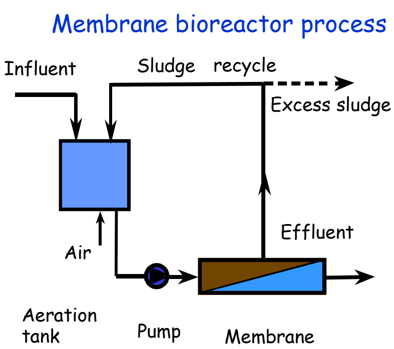
Sezione Ambientale

Membrane bioreactors – What are they? - 1

2

Membrane Bioreactors





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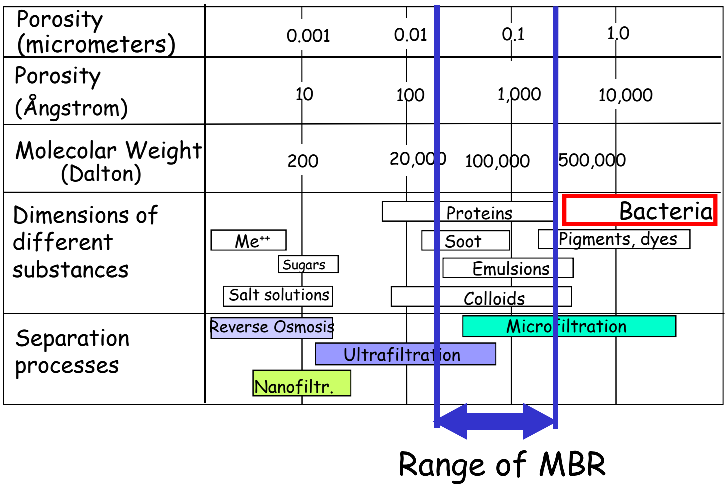
Membrane bioreactors – What are they? – 2

3



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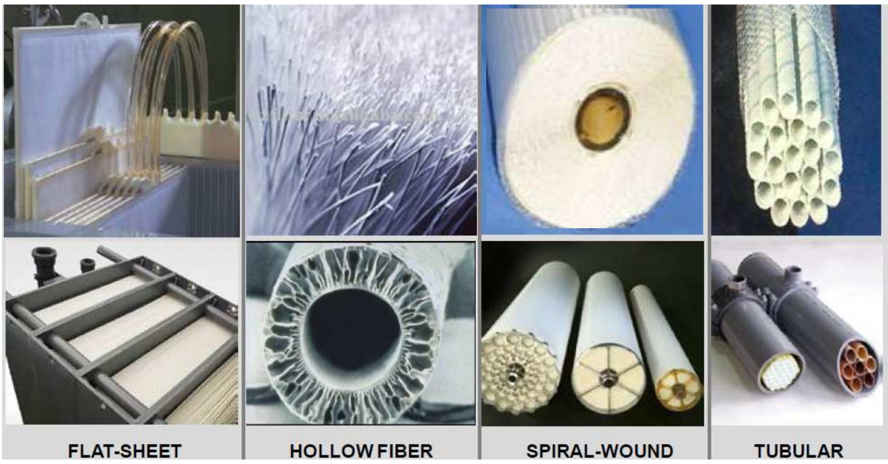
Membrane bioreactors – What are they? – 3

4



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Membrane bioreactors – What are they? – 4

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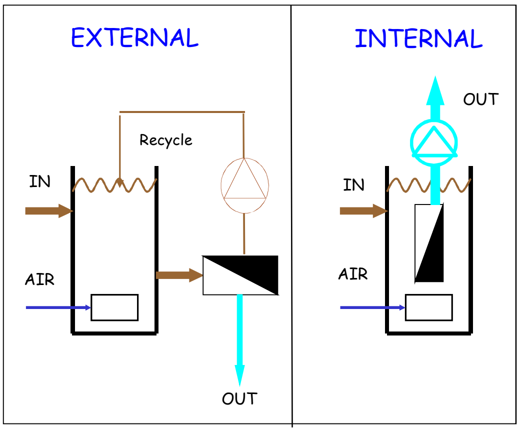

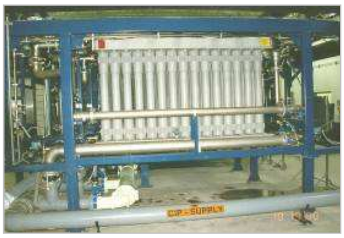

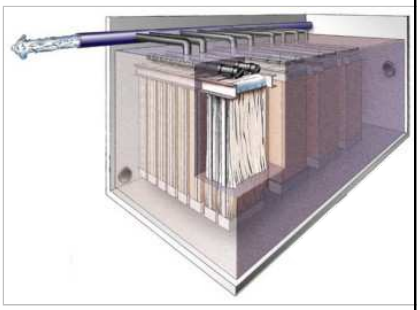

Difference between the two:
How filtration is operated and
Cleaning methods

Membrane bioreactors – Milestones 1

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1969 – 1985: Research

1969 – Lab scale

Smith, C. W., Di Gregorio, D., and Talcott, R. M. (1969).
The use of ultrafiltration membrane for activated sludge separation. Proceedings of the 24th Annual Purdue Industrial Waste Conference, Purdue University, West Lafayette, Indiana, USA. 1300–1310.

1971 – Dorr Oliver MBR shipboard systems

Bemberis I., et al. (1971) Membrane sewage treatment systems-potential for complete wastewater treatment, Pamer. Soc. Agric. Eng. Winter Mtg, 71-878, 1-28.

1985 – Dorr Oliver concept of anaerobic side stream MBR systems

Li A., et al., 1985, Application of membrane anaerobic reactor system (MARS) for treatmetnt of industrial wastewaters. Proc. 39th Ind. Waste Conf., Purdue University, Lafayette, Indiana, USA, May, 627-636

The 90's: Prototypes

1989 – First hollow fiber (HF) UF MBRs

Yamamoto K, Hiasa H, Talat M, and Matsuo T (1989) Direct solid liquid separation using hollow fiber membranes in activated sludge aeration tank. Water Science and Technology 21: 43--54.

1991 – First flat sheet (FS) UF MBRs

Ishida, H., Yamada, Y., Tsuboi, M., and Matsumura, S. (1993). Submerged membrane activated sludge process (KSMASP) — its application into activated sludge process with high concentration of MLSS. Proceedings of the 2nd International Conference on Advances in Water and Effluent Treatment

1993 – Kubota (FP), Mitsubishi (SUR) and Zenon (ZW145-50): first commercial MBRs

Membrane bioreactors – Milestones 2

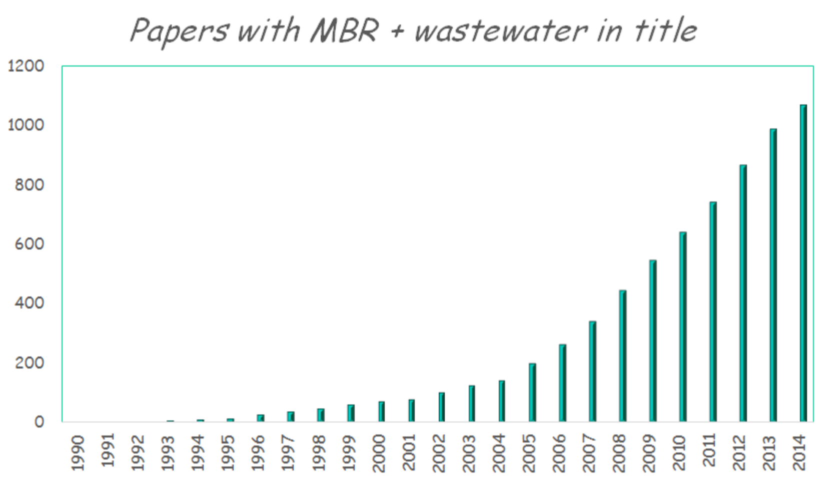
From 2000: Commercial development

- Microdyn-Nadir BioCel (FS, D)
- HuberVRM (FS, D)
- Toray (FS, J)
- MemStar (HF, PRC)
- Econity (HF, South Korea)
- Anaergia FiberPlate (HF, Canada)
- Puron (now Koch Membrane System - KMS)
- Zenon ZW-500d (HF, CN, now GE, USA)
- US Filter MemJet (HF, USA)

From 2008: Optimization

- Siemens Memcor MemPulse (now Evoqua HF, USA)
- Puron-KMS PVDF module (HF, USA)
- GE LEAP MBR (HF, USA)
- Kubota RW type 300, 200, 150 (FS, J)
- *…& others*

Membrane bioreactors – Trend of technical papers



Membrane bioreactors – Books and websites

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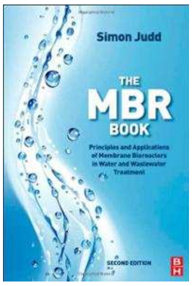
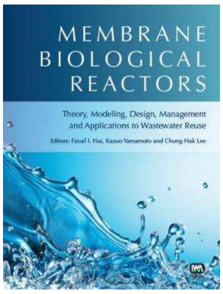
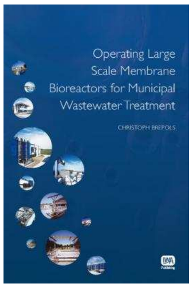
Judd, 2011



Hai et al. 2013 (IWA)



Brepols, 2010 (IWA)



WEF Manual of Practice no. 36, 2012

http://www.mbr-network.eu/mbr-projects/downloads-common.php

MBR membrane bioreactors www.thembrsite.com

Home | Principles | Membrane Process | MBR Design | Fouling | Module Optimization | Nutrient Removal | Cost | Miscellaneous www.onlinembr.info/

Membrane bioreactors – Market share

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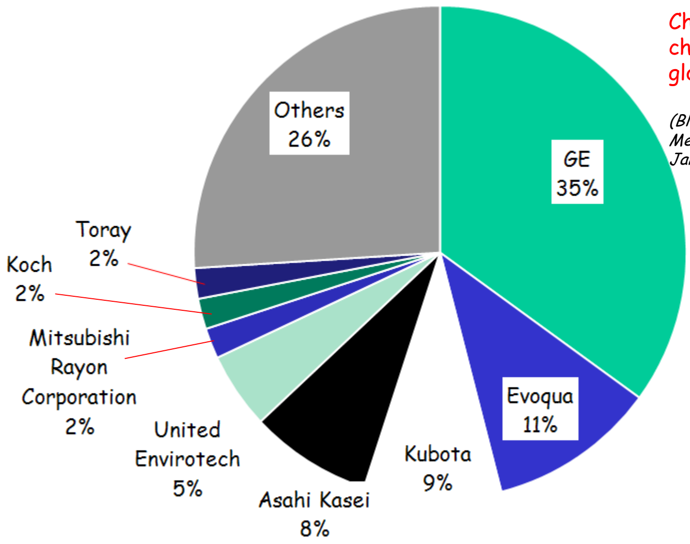
CAGR: Compound Annual Growth Rate

	$ Billion	Market Share (%)	CAGR 2010-2015 (Low (<5%) / Med (5-8%) / High (> 8%))
Membrane Bioreactors (MBR)	0.7	1.9	Very High
RO	1.8	5.1	High
MF	1.0	2.8	High
UF	1.2	3.5	High
NF	0.4	1.3	Med
UV	0.5	1.6	High
Ozone	0.1	0.6	High
UASB (Municipal)	0.2	0.5	High
Chlorination	1.1	3.5	Med
Demineralisation	0.8	2.4	Med
WW Pre-Treatment	1.4	4.2	Low
W&WW Clarifiers	3.5	9.9	Med
Other Primary WW	3.8	11.1	Med
Activated Sludge	3.7	10.7	Med
Other Biological WW	4.0	10.9	Med
Sludge Thickening	1.5	4.4	Low
Sludge Dewatering	1.8	5.2	High
Sludge Digestion	0.7	2.0	High
Sludge Drying	0.7	2.0	High
Filtration	5.5	16.0	Med

Membrane bioreactors – Market share

Surface of installed membranes (Frost & Sullivan, 2008)



Chinese suppliers are the chief threat to GE Water's global MBR position

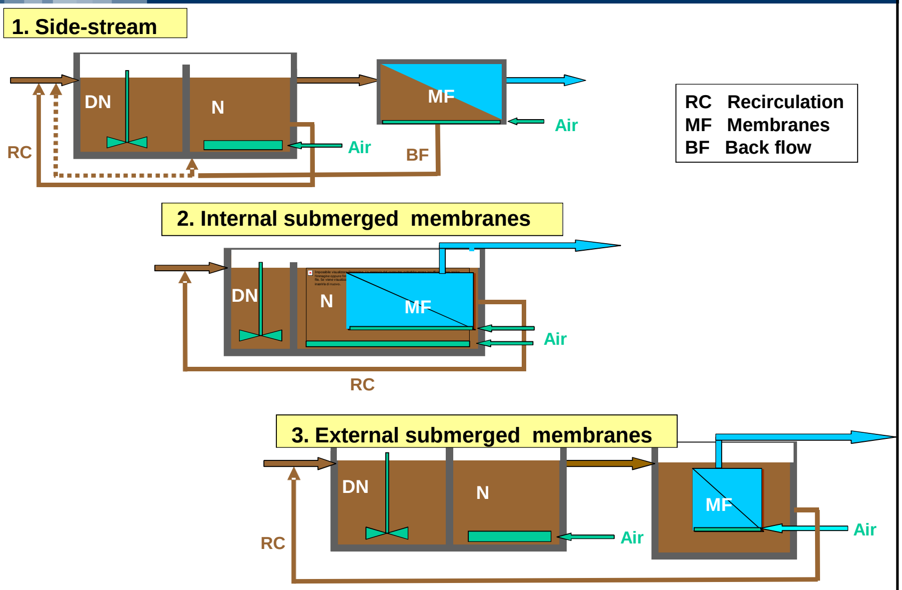
(Bluefield Research, 'Global Membrane Bioreactor Market', January, 2014)

Membrane bioreactors – Polymeric membranes

Hollow fiber membrane
(e.g.: GE, USA)

Flat plate (or flat sheets) membrane
(e.g.: Kubota, Japan)

Membrane bioreactors - Example of plant configurations



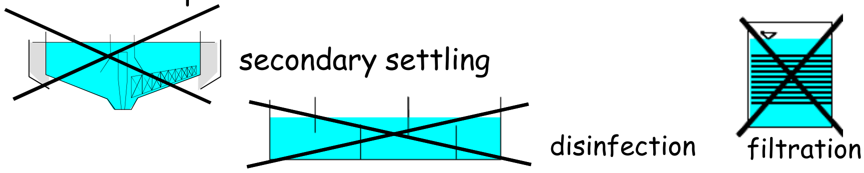
Membrane bioreactors vs CAS

Membrane:
solid-liquid separation device
(instead of gravity settling)

- SRT independent from HRT
- SS concentration: 3 to 4 times higher than in CAS processes
- Biomass selection

does not occur by settling ability,
BUT
on adaptation to process conditions and available substrate

In an MBR process these units are not needed



Membrane bioreactors vs CAS

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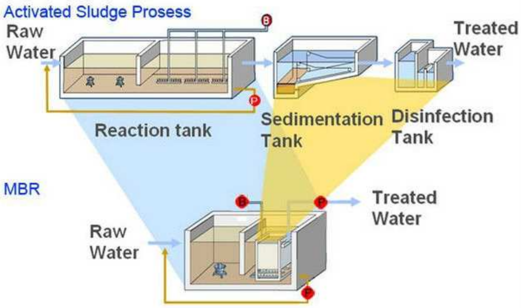
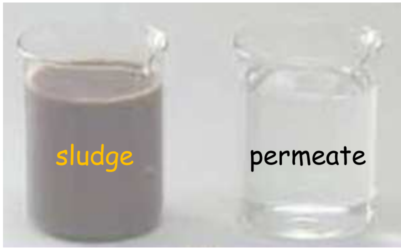
CLAIM: MBR are better than CAS because:

- ❖ Bulking and biological foams are no longer a problem
- ❖ Stricter effluent limits can be met
- ❖ Revamping and upgrading can be done with little room available





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Membrane bioreactors – Challenges

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- ❑ Fouling (and cleaning)
- ❑ Energy demand (mainly for aeration)
- ❑ Investment and operating costs

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Membrane bioreactors – Fouling ("Achille's heel of MBRs") 17

" *The process resulting in* ***loss of performance of a membrane*** *due to the* ***deposition*** *of suspended or dissolved substances* ***on its external surface***, ***at its pores openings*** *or* ***within its pores*** "

William J. Koros, 1996, JMS

Georgia Institute of Technology

Membrane bioreactors – Fouling – 1 18

According to Zhang *et al. (JMS, 2006, 284, 54-66)*

- 1st stage – Conditioning
  - **Fouling even @ no flux** (passive adsorption of macromolecules)
  - **Initial pore blocking**
- 2nd stage – Steady-state Fouling
  - **Cake** formation
  - **Biofilm** growth
  - **Further pore blocking** (removable by chemical and physical cleaning)
- 3rd stage (to be avoided) – **TMP jump**
  permeability collapses; J > critical J (severe irreversible fouling)

Membrane bioreactors – Fouling – 2

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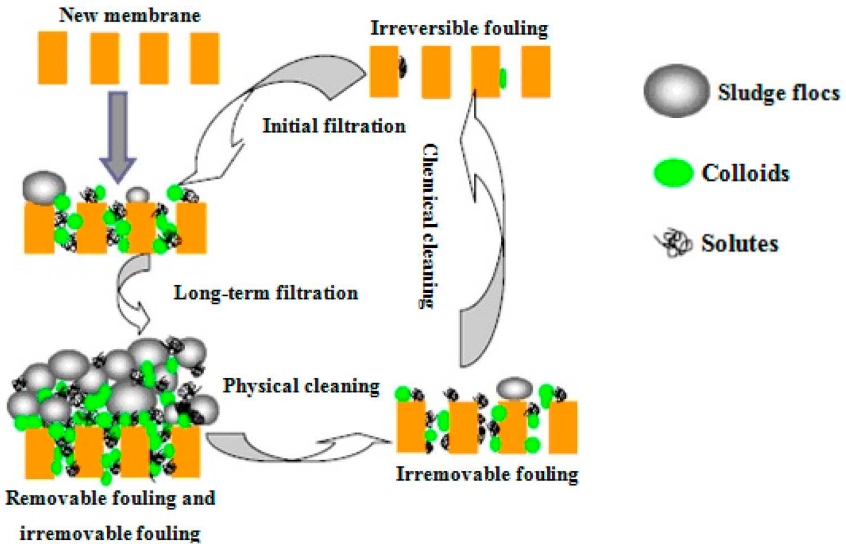

SOURCE: Meng, F.; Chae, S.-R.; Drews, A.; Kraume, M.; Shin, H.-S.; Yang, F. Recent advances in membrane bioreactors (MBRs): Membrane fouling and membrane material. Water Res. 2009, 43, 1489–1512.

Membrane bioreactors – Fouling – 3

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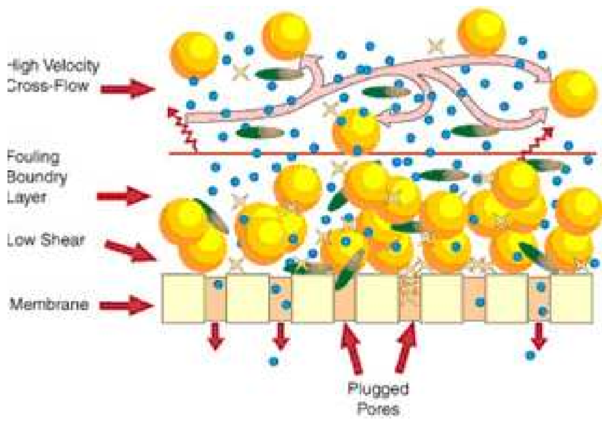
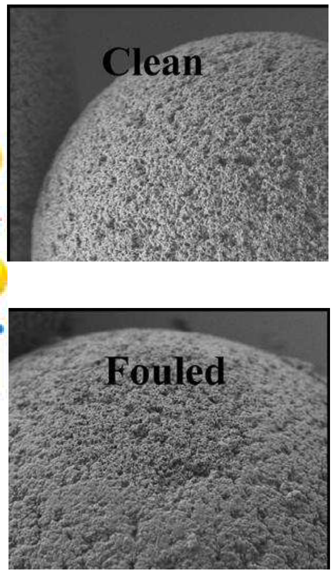
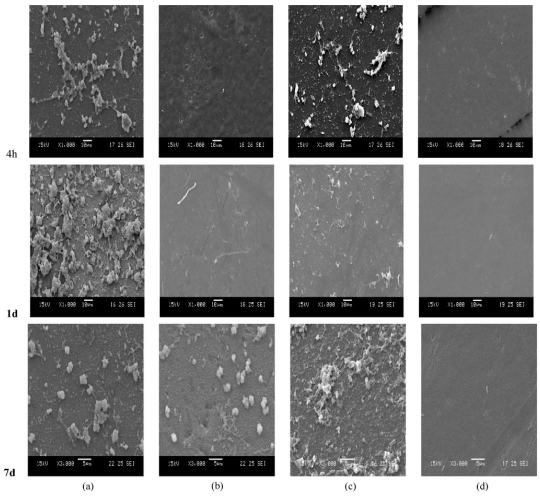




Membrane bioreactors – Fouling – 4: New developments



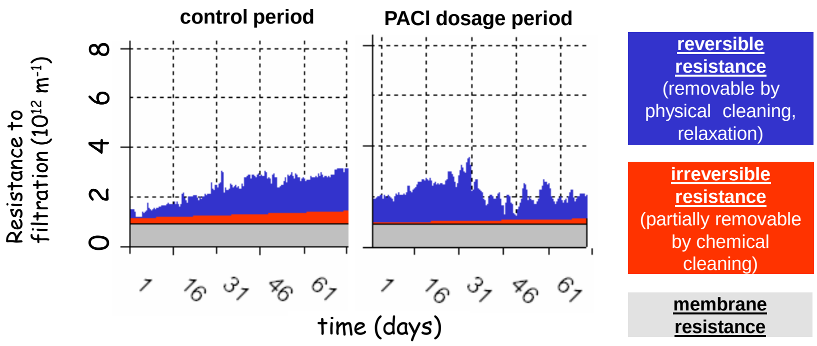
Membrane treated to induce low-fouling properties

- Plasma treatment
- *Antifouling materials*
- Surface modification with nanoparticles

Liu, C.X.; Zhang, D.R.; He, Y.; Zhao, X.S.; Bai, R. Modification of membrane surface for anti-biofouling performance: Effect of anti-adhesion and anti-bacteria approaches. *J. Membr. Sci.* **2010**, *346*, 121–130
Petros K. Gkotsis, Dimitra Ch. Banti, Efrosini N. Peleka, Anastasios I. Zouboulis and Petros E. Samaras Fouling Issues in Membrane Bioreactors (MBRs) for Wastewater Treatment: Major Mechanisms, Prevention and Control Strategies, *Processes*, **2014,** 2(4), 795-866; doi:10.3390/pr2040795

Membrane bioreactors – Fouling – 5: Flux enhancers

PACl addition for fouling control



- more stable filtration process
- reduction (- 45%) of the irreversible fouling rate

Other flux enhancers:

- cationic polymers
- activated carbon

Membrane bioreactors – Critical / sustainable flux

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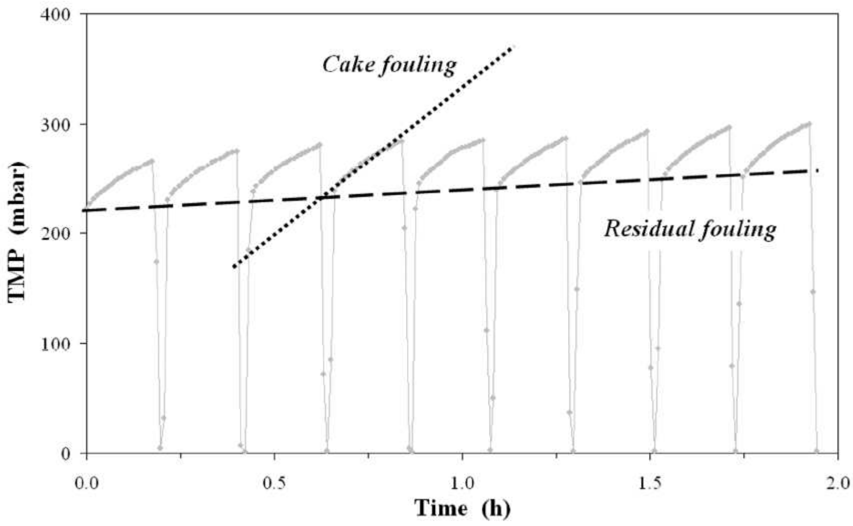

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Membrane bioreactors – Critical / sustainable flux

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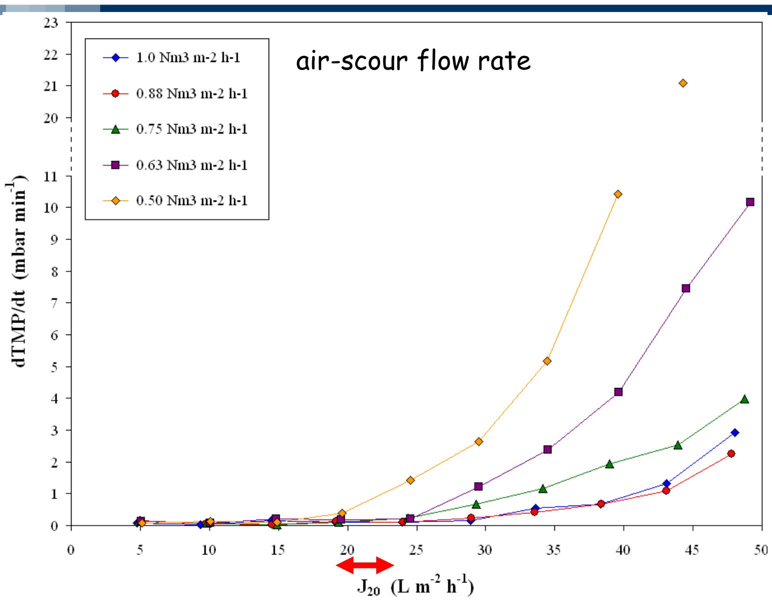

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Membrane bioreactors - Backwash

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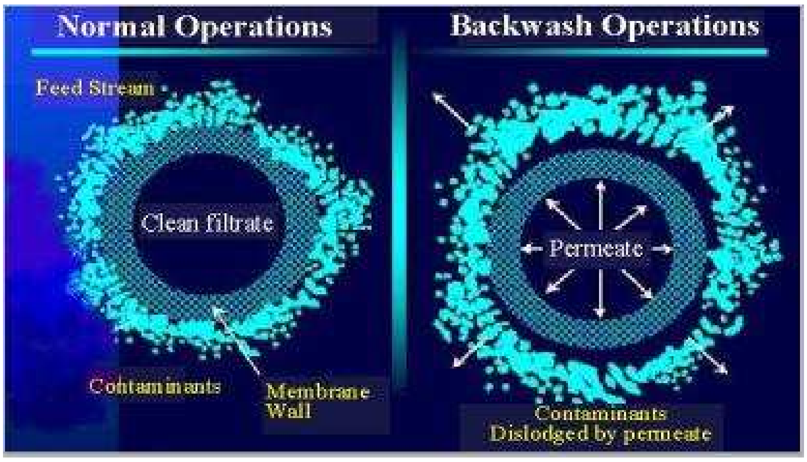
Periodical backwash



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Membrane bioreactors - Relaxation

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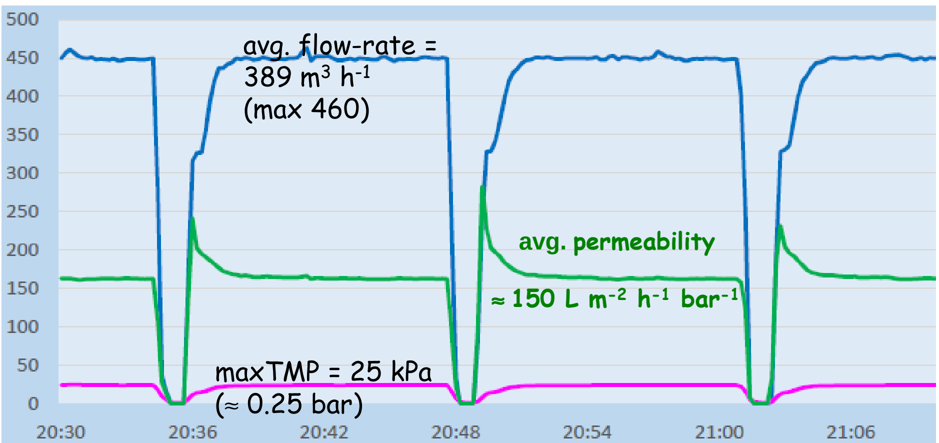

T = 25.8°C

time (hour:min)

1 min over 12 min

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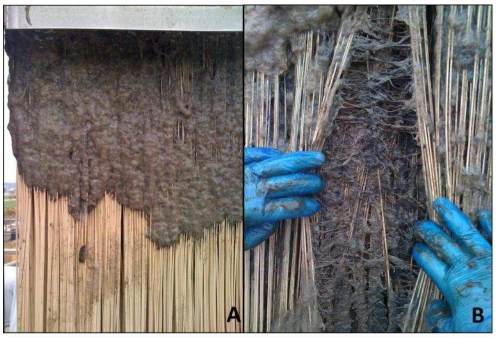
Membrane bioreactors – Clogging



Membrane bioreactors – Cleaning - 1

Borghetto S. Spirito (Ligurian Sea, Italy)

At present the MBR modules treat 25.000 AE (Q_m = 280 m^3 h^{-1})

Cleaning Service	No. per year	HClO (L)	Citric acid (L)
Planned maintenance washings	192	11.500	-
Emergency washings	4	250	-
Soak and wash	16	6.900	3.500
Total	212	19.000	3.500

Membrane bioreactors – Cleaning - 2

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Empty the tank .... then soak

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Membrane bioreactors – Cleaning - 3

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... and wash

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Membrane bioreactors – Cleaning – 4

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Membrane bioreactors – Cleaning – 5

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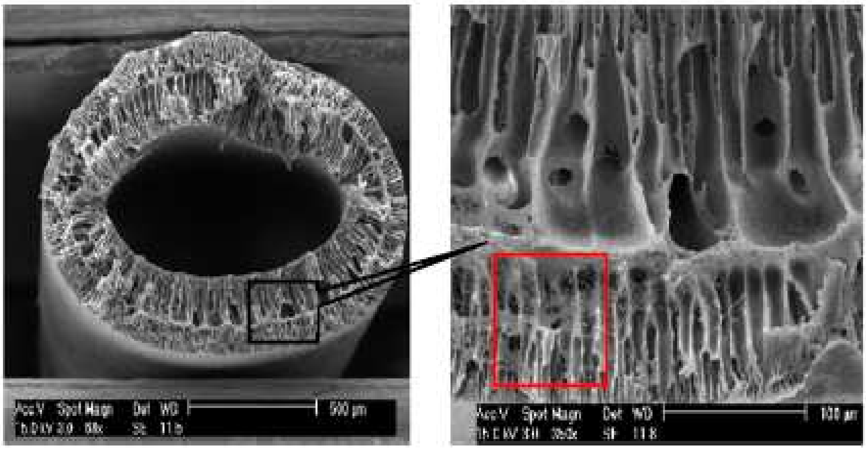

HF membrane after physical cleaning

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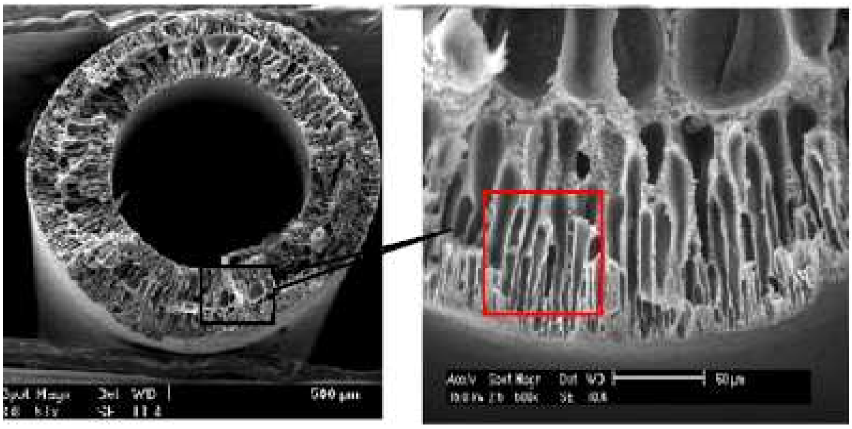
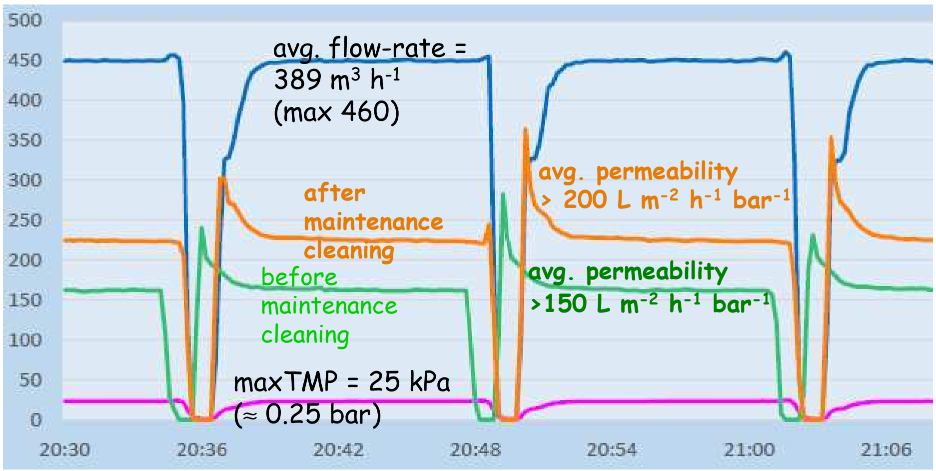
Membrane bioreactors – Cleaning – 6



HF membrane after physical AND chemical cleaning
Source: Li et al., 2014

The Membrane Fouling Monitored by Scanning Electron Microscopy (SEM) in a Submerged Membrane Bioreactor
Journal of Water Sustainability, Volume 4, Issue 3, September 2014, 159-166

membrane bioreactors – Cleaning – 7



T = 25.8°C

time (hour:min)

Membrane bioreactors - Pretreatments

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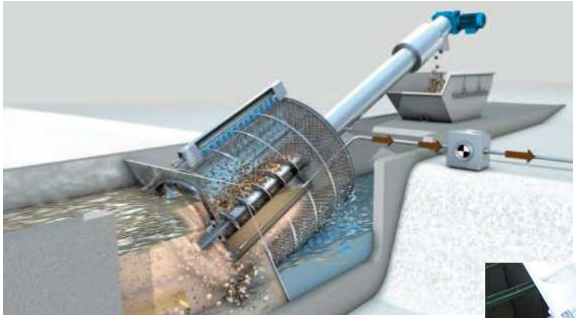

rotating fine screens
are a "must", to prevent failures
(spacing: 0,75 to 2 mm)

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Membrane bioreactors - Management of variable flow rates

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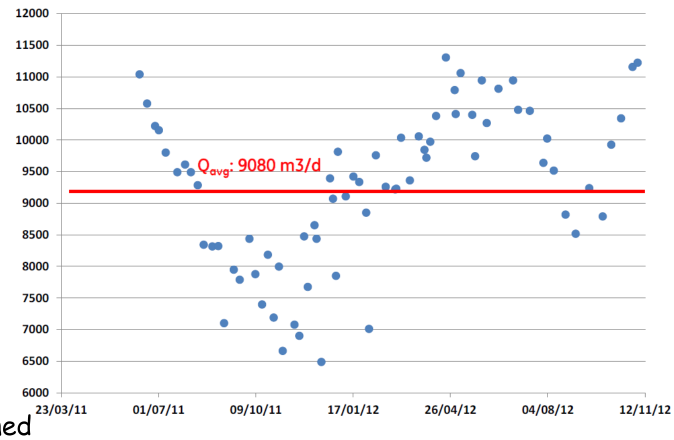
MBR can cope with 2-fold variation



Dry weather:
equalization tanks
may be useful

Wet weather flowrates in combined
sewer systems:
side stream treatments
may be required

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Membrane bioreactors – Aeration - 1

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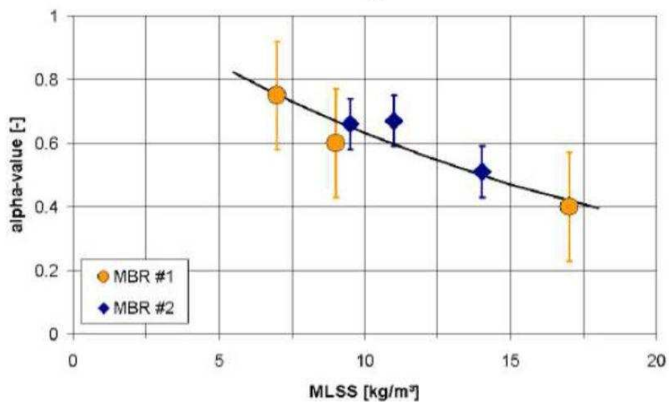
α-values: The α-value is defined as the ratio of the volumetric transfer coefficient under process condition to the clean water transfer coefficient (equation below).

$$\alpha = \frac{k_L a_{processwater}}{k_L a_{cleanwater}}$$

Figure 3 – α-values for the fine bubble aeration system vs. MLSS



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Membrane bioreactors – Aeration - 2

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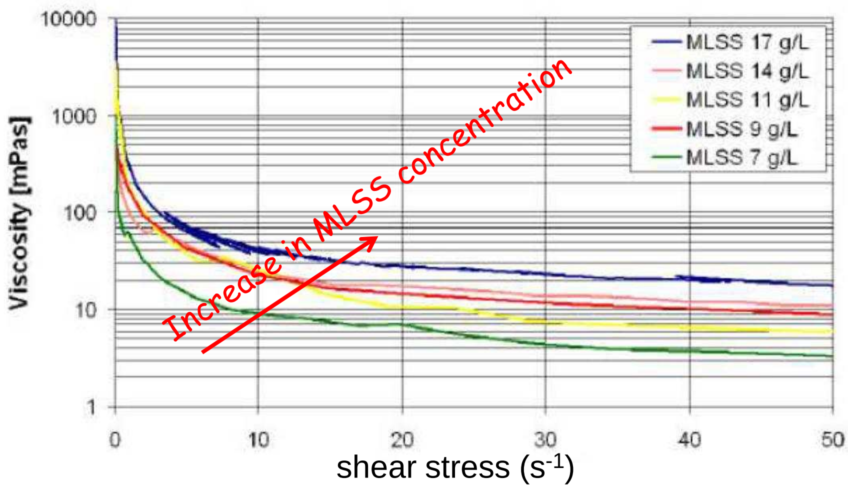
Dynamic viscosity vs. shear stress of MBR sludge at different MLSS



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Membrane bioreactors – Aeration - 3

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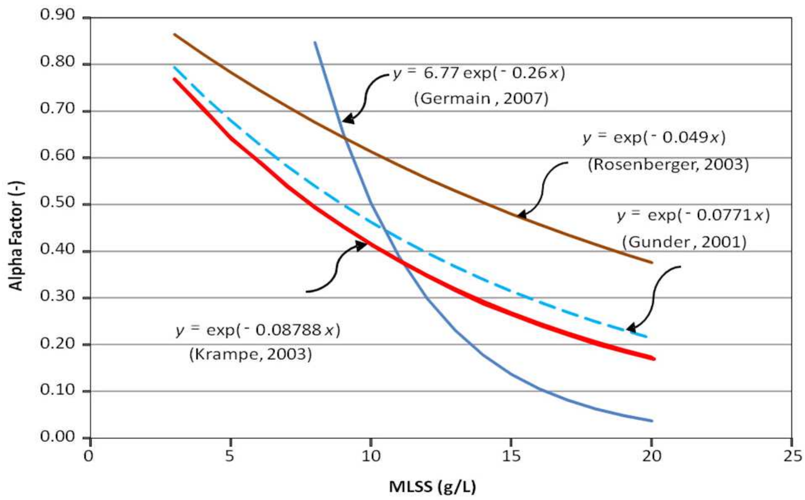

http://onlinembr.info/MBR%20Design/MLSS%20and%20viscosity.htm

Membrane bioreactors – Trend of performance

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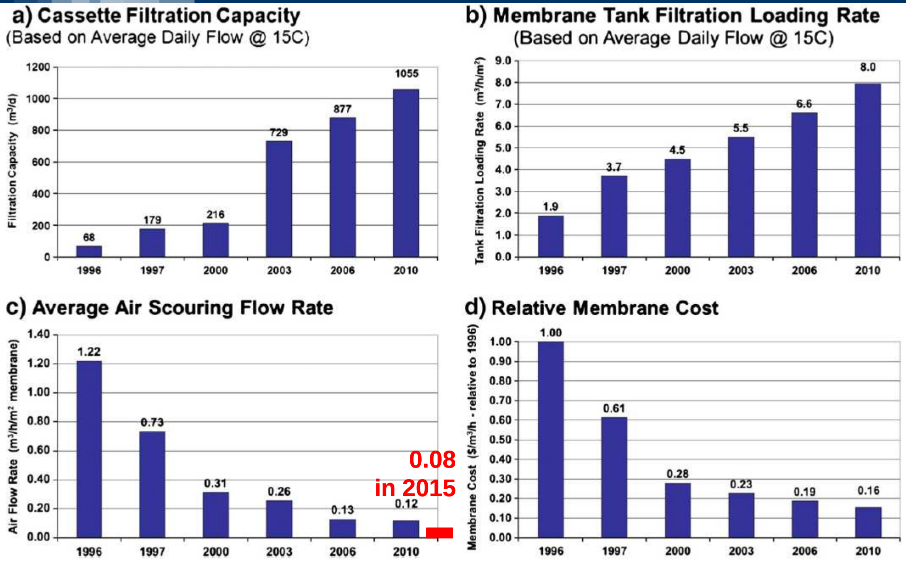

Da: Cote et al. (2012) Hollow fiber membrane life in MBR, Desalination, 288, 145-151

Membrane bioreactors – Energy consumption – 1

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Treatment unit	Specific energy (kWh/m^3)
Pre-treatments	0.03
Nitrification - denitrification	0.20
MBR units	0.23
Others (aerobic sludge stabilization, thickening and dewatering, odour control, general plant services)	0.21
TOTAL	**0.67**

WWTP Borghetto S. Spirito, 2014

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Membrane bioreactors – Energy consumption – 2

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Energy consumption of the Vasserveld MBR; Bentem, 2010
http://www.onlinembr.info/Cost/iMBR_OPEX.htm

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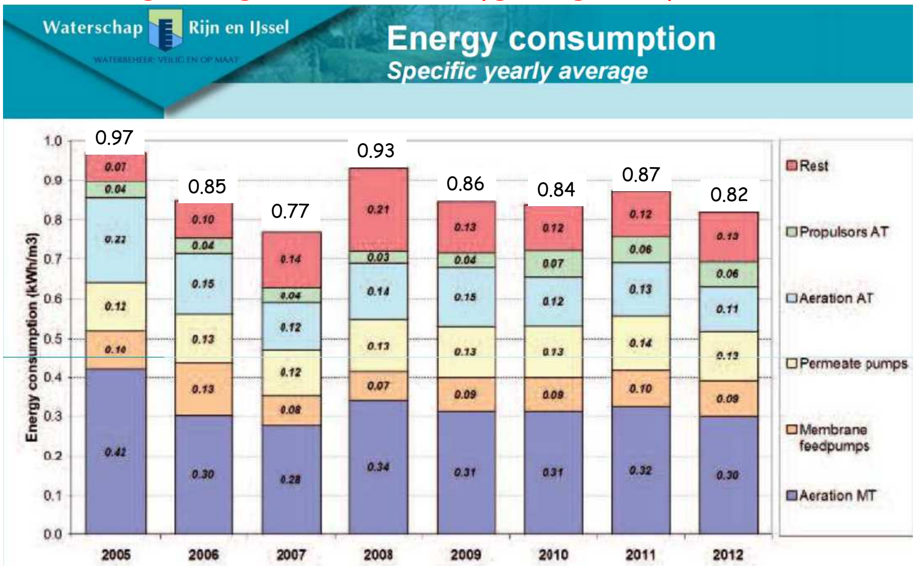
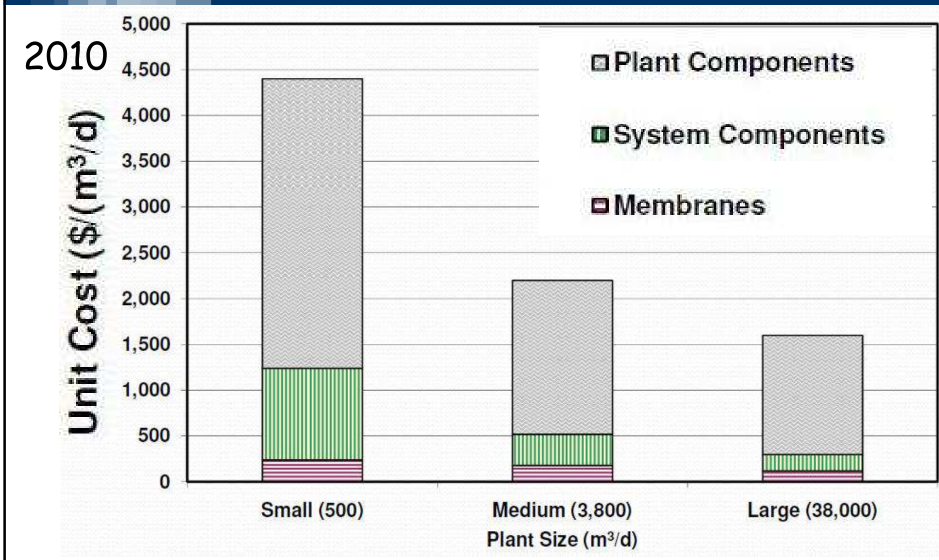
membrane bioreactors – Energy consumption – 3

… but things changed, and neither upgrading nor optimization went on



Membrane bioreactors – Investment costs – 1



http://www.onlinembr.info/Cost/iMBR_CAPEX.htm

Membrane bioreactors – Investment costs – 2

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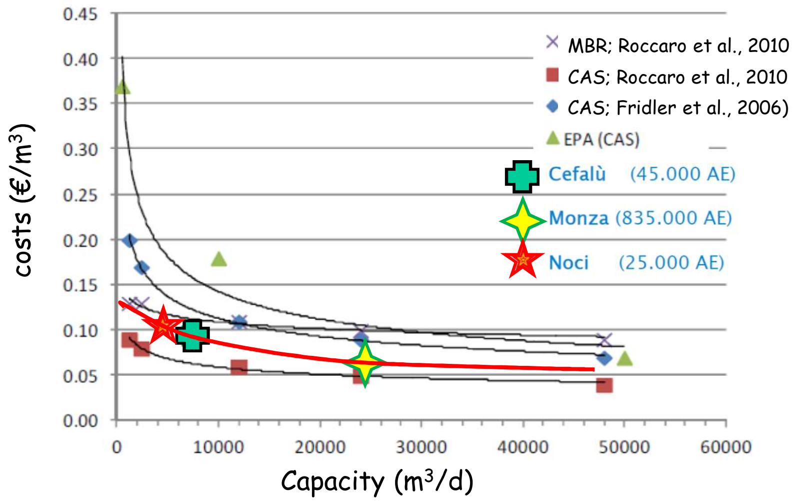

Source: Campagna M., Roccaro P., Vagliasindi F.G.A. (2012) Costi di gestione e di realizzazione di impianti MBR, in BIOREATTORI A MEMBRANE PER IL TRATTAMENTO DELLE ACQUE REFLUE, by Vincenzo Naddeo,Vincenzo Belgiorno, modif. A. Schiavone (FAST, January 2015)

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Membrane bioreactors – Operating costs – 1

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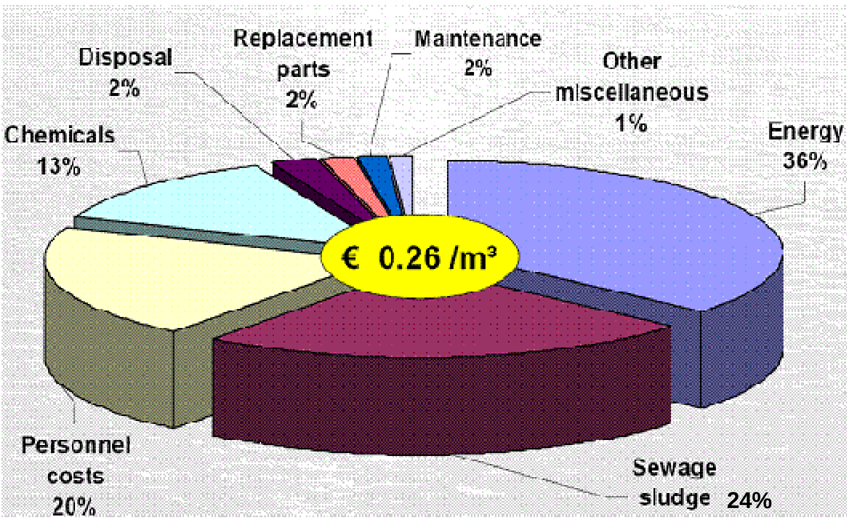

Operating cost breakdown of municipal MBR in Nordkanal, Germany, 2006 (80.000 PE; 45.000 m³/d; Engelhardt, 2008); http://www.onlinembr.info/Cost/iMBR_OPEX.htm

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Membrane bioreactors - Operating costs - 2

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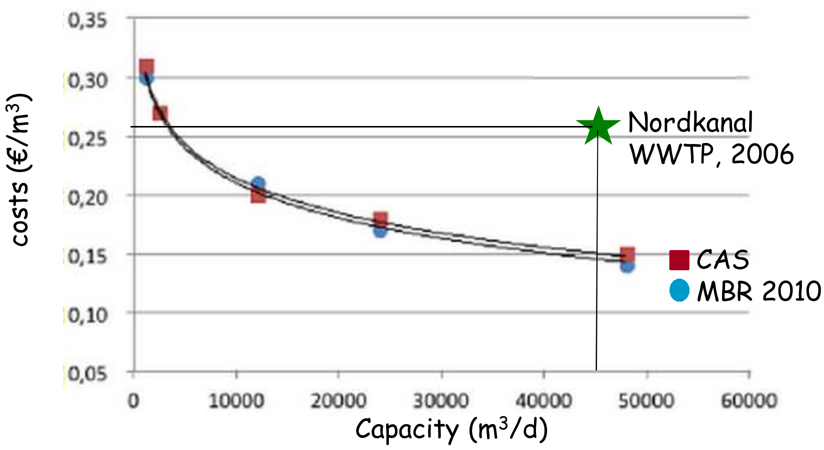

Source: Campagna M., Roccaro P., Vagliasindi F.G.A. (2012) Costi di gestione e di realizzazione di impianti MBR, in BIOREATTORI A MEMBRANE PER IL TRATTAMENTO DELLE ACQUE REFLUE, by Vincenzo Naddeo,Vincenzo Belgiorno

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Membrane bioreactors - Trend of costs

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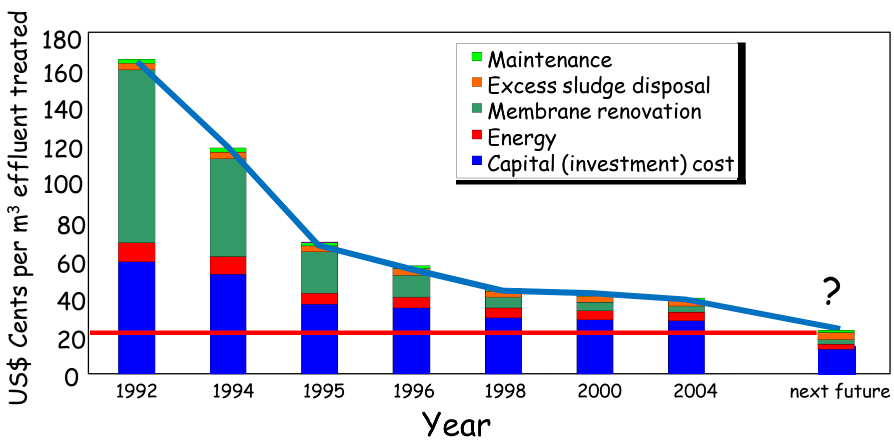

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Membrane bioreactors – HF: Strengths and lessons learned

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- Advantages of HF vs SF:
  - Higher packing density ➔ lower footprint
  - High flexibility ➔ better adaptation to local needs
  - Lower energy required for air scouring
  - Can sustain effective backwashing
- Lessons learned:
  - Risk of membrane abrasion
  - Ragging inside the cassette →
  - Possible delamination
  - Higher risk of debris accumulation
  - In some cases (high ΔT) slack-adjustment is necessary
  - Fiber may slip-off from top header

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Membrane bioreactors – SF: Strengths and lessons learned

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- Advantages of SF vs HF:
  - Lower fouling potential by debris (fibers, rags, hair)
  - Lower TMP applied (or higher LMH at same TMP)
  - Lower consumption of chemicals
- Lessons learned:
  - Lower *packing-density* → *higher footprint*
    → *internal submerged configuration may be the only design choice*
  - Risk of uneven flux distribution
  - Backwash may be unefficient
  - De-lamination risk even at low backwashing pressure

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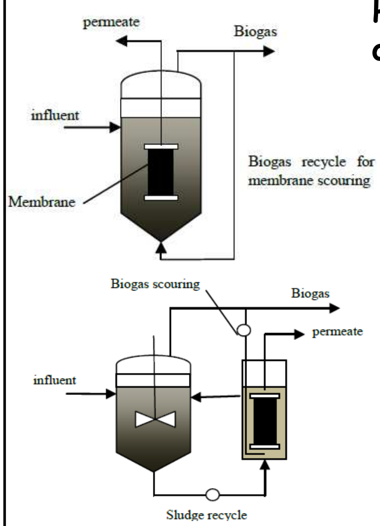
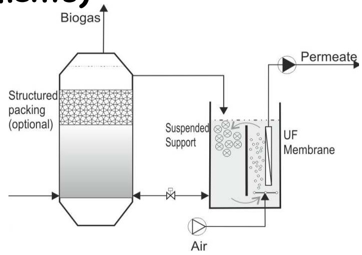
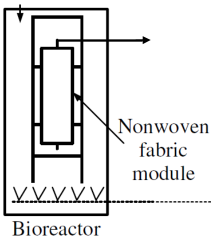
Membrane bioreactors – Possible future developments – 1 51

Hybrid (combination of MBR and other treatments)



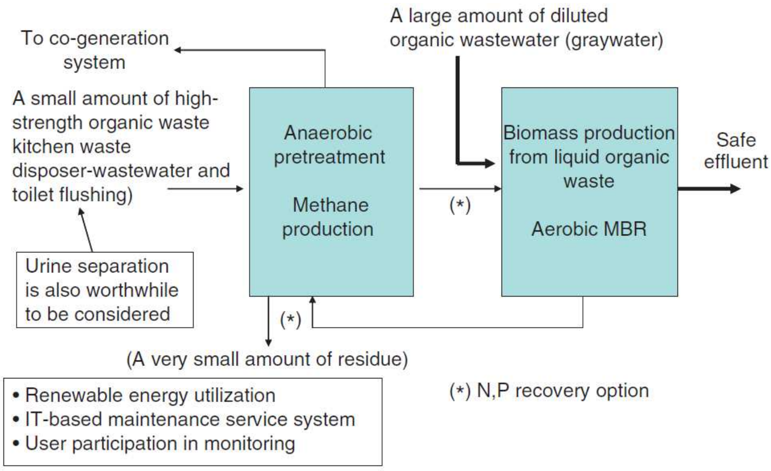
Anaerobic MBRs





Non-woven membranes

Membrane bioreactors – Possible future developments – 2 52



Next-generation MBR system: anaerobic combination for on-site small-scale advanced treatment.

F I. Hai and K Yamamoto, Membrane Biological Reactors, 2011
http://ro.uow.edu.au/cgi/viewcontent.cgi?article=2198&context=scipapers

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Thank you for your attention

Acknowledgements
Giuseppe Guglielmi (formerly at ETC srl, now at Koch Membrane Systems) and **Aronne Teli** (DICA, Environmental Section) **kindly provided some of the slides**

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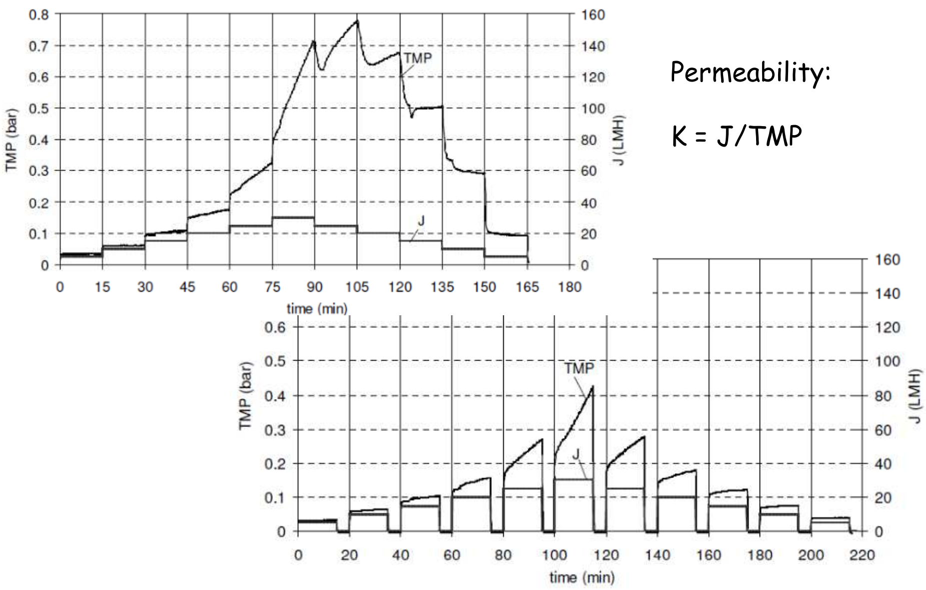
http://www.dica.polimi.it/en/sezioni/ambientale/
http://hidroinformatics.polimi.it

Membrane bioreactors – TMP and Flux 54



Permeability:

K = J/TMP