MBR-Network

Final MBR-Network Workshop

"Salient outcomes of the European R&D projects on MBR technology"

Presentation handouts

31 March – 1 April, Berlin 2009 (Germany)

Hosted by KOMPETENZZENTRUM Wasser Berlin

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R. Mehrez, M. Ernst, V. Iversen, A. Drews, M. Kraume, M. Jekel

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Development and application of a proteins and polysaccharides sensor for on-line fouling control in membrane bioreactors

R. Mehrez*, M. Ernst, V. Iversen***, A. Drews***, M. Kraume***, M. Jekel***

Technische Universität Berlin,
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** Centre for Water in Urban Areas
*** Chair of Chemical Engineering

Final Workshop MBR-Network
Membrane Technology for Wastewater Treatment
Wasser Berlin, 31st March -1st April 2009

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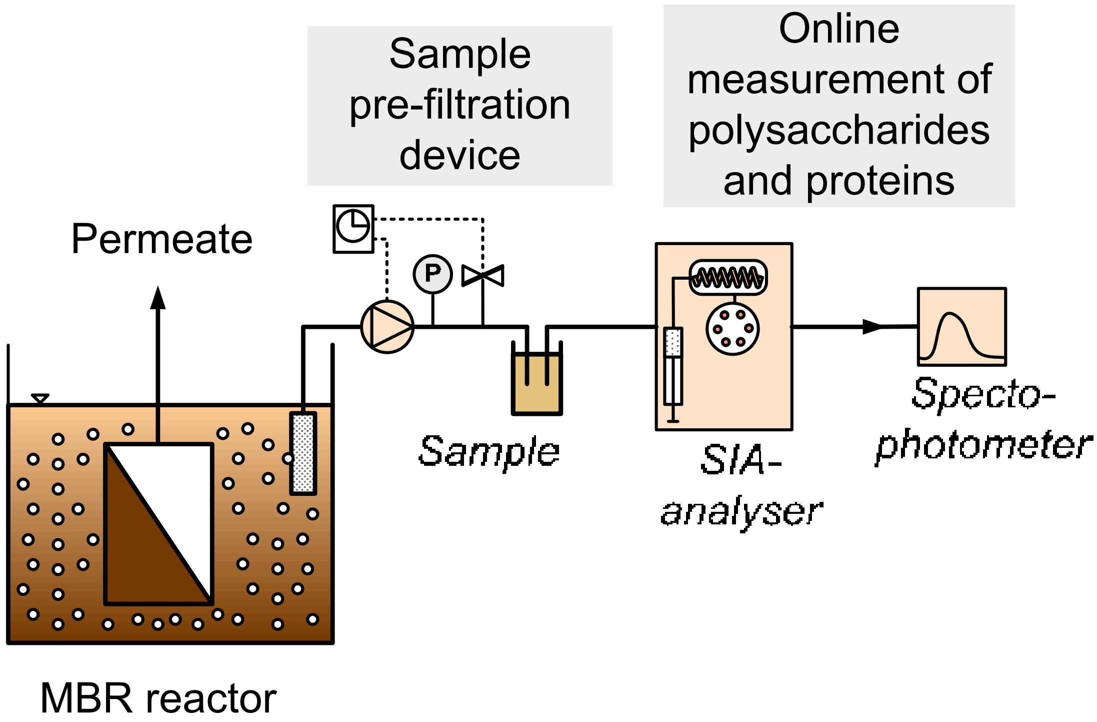
On-line sensor



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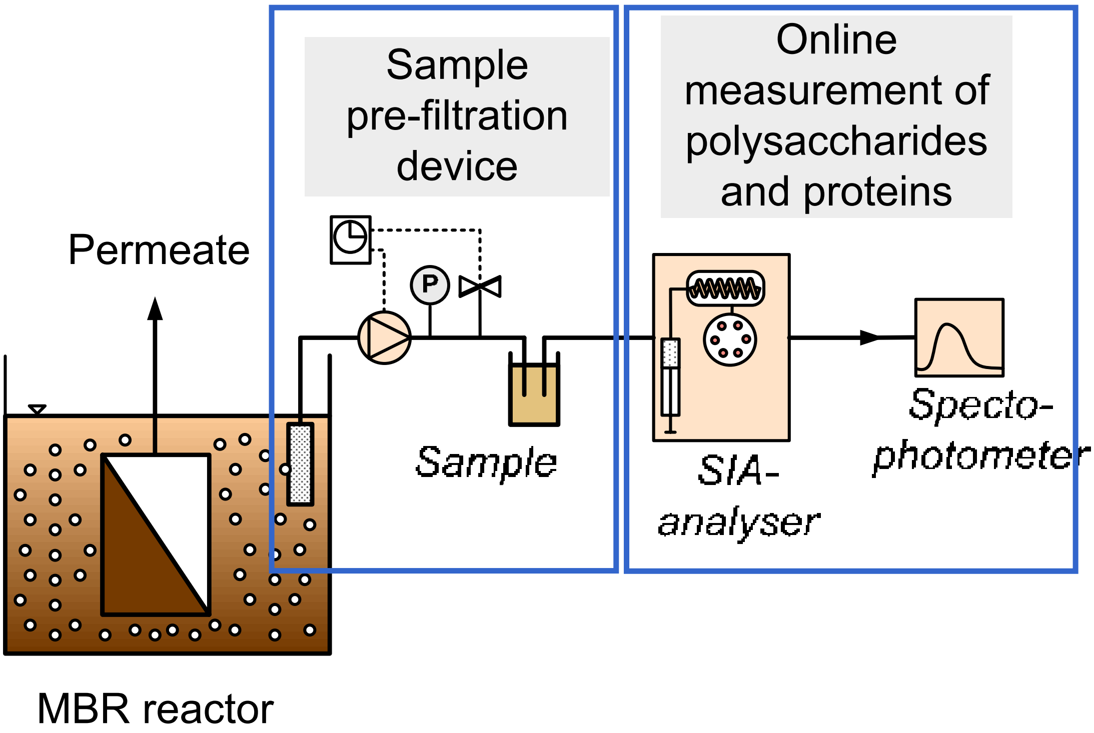
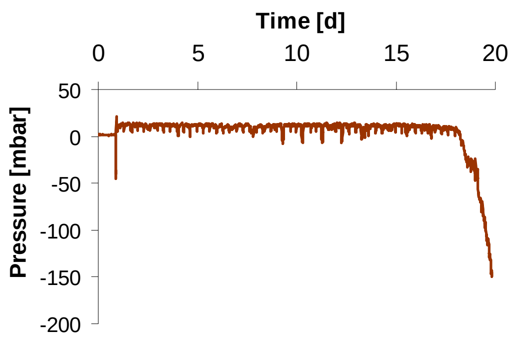
On-line sensor



Sample pre-filtration device

- Filter: stainless steel, ø1µm, ~50 cm^2
- Filtration mode out / in
- Filtration/Relaxation: 10min/2min
- Comparable separation to manual sludge sample filtration (paper filter)



- Filter run-time ~ 10-20 days
- Sample volume 45-60 mL/h (measurement each 3 – 4h)

More details → see poster

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Photometric methods

PROCEDURE	PROTEINS *Modified method of Lowry*	POLYSACCHARIDES *Method of Dubois*
SAMPLE	conc.: 15-30 mg/L	conc.: 5-20 mg/L
+ REAGENT 1	+ alkaline copper solution with chelating agent (NTA)	+ phenol solution
MIXING		
+ REAGENT 2	+ Folin-Ciocalteu-phenol	+ H_2SO_4 (97%)
MIXING		
MEASUREMENT OF ABSORPTION	750 nm	490 nm

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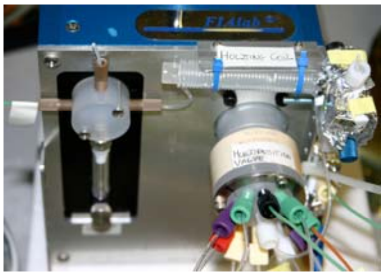
SIA - Sequential Injection Analysis



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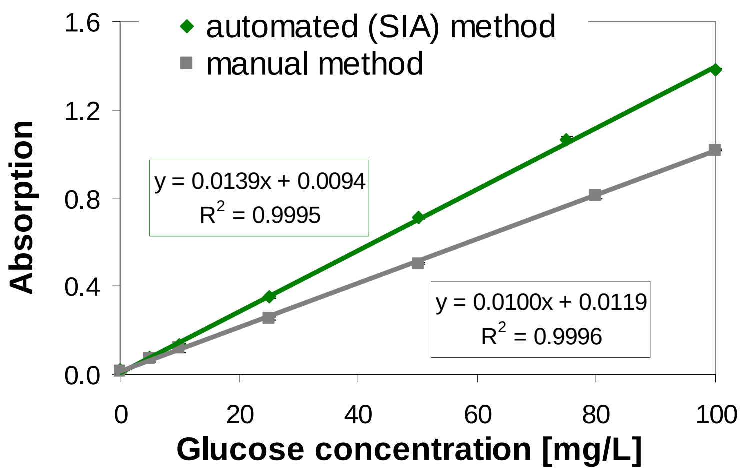
MEASUREMENTS WITH STANDARD SOLUTIONS

Polysaccharides - Calibration curve



	SIA	Manual
Detection limit	0.9 mg/L	1.2 mg/L
Quantification limit	3.4 mg/L	4.2 mg/L
Measurement error (SD) (glucose 10 mg/L)	± 0.5 mg/L	± 0.5 mg/L

More details → see poster

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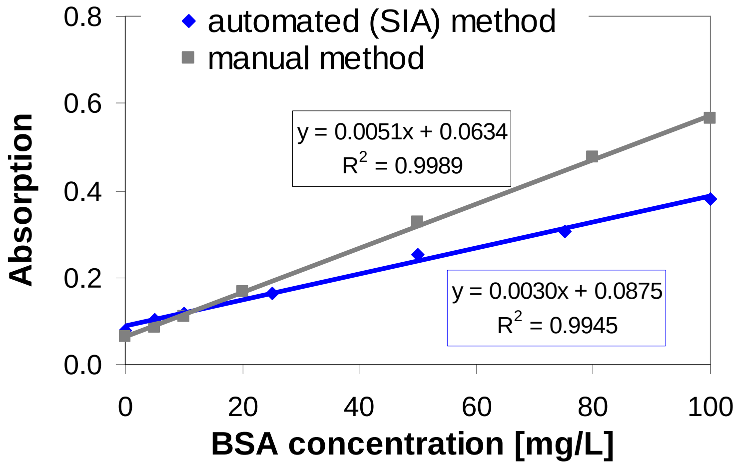
Proteins - Calibration curve



	SIA	Manual
Detection limit	3.9 mg/L	1.0 mg/L
Quantification limit	13.5 mg/L	3.3 mg/L
Measurement error (SD) BSA 20 mg/L	± 2.0 mg/L	± 0.2 mg/L

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MEASUREMENTS ON THE PILOT PLANT

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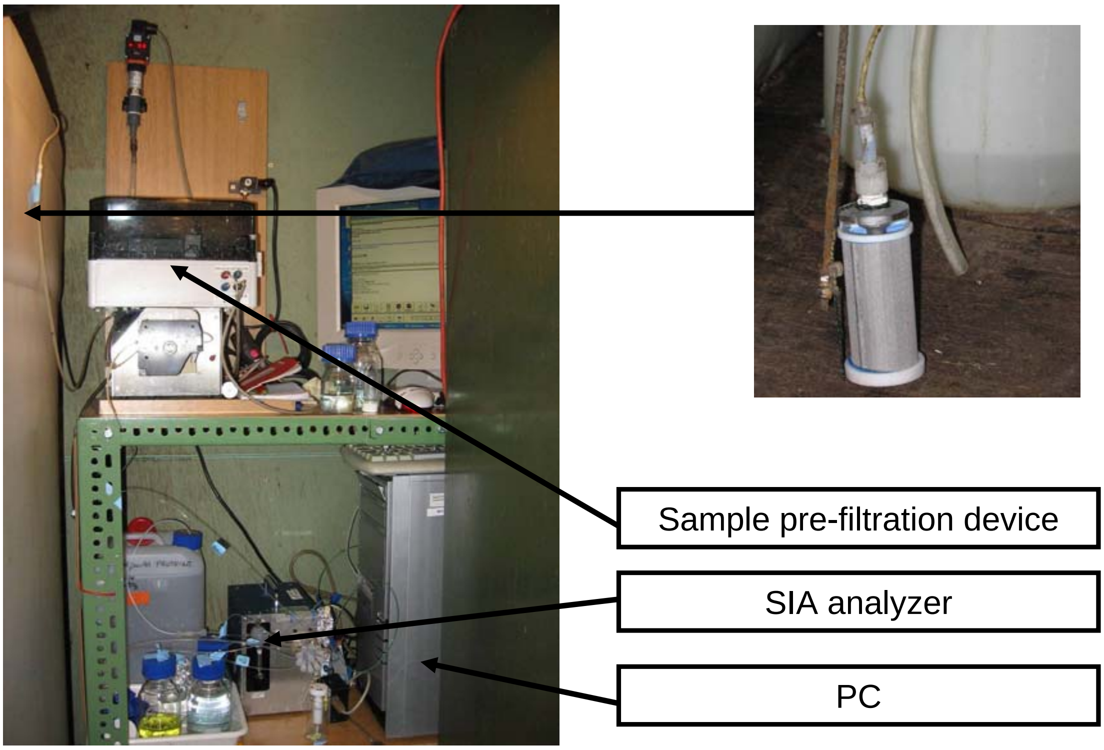
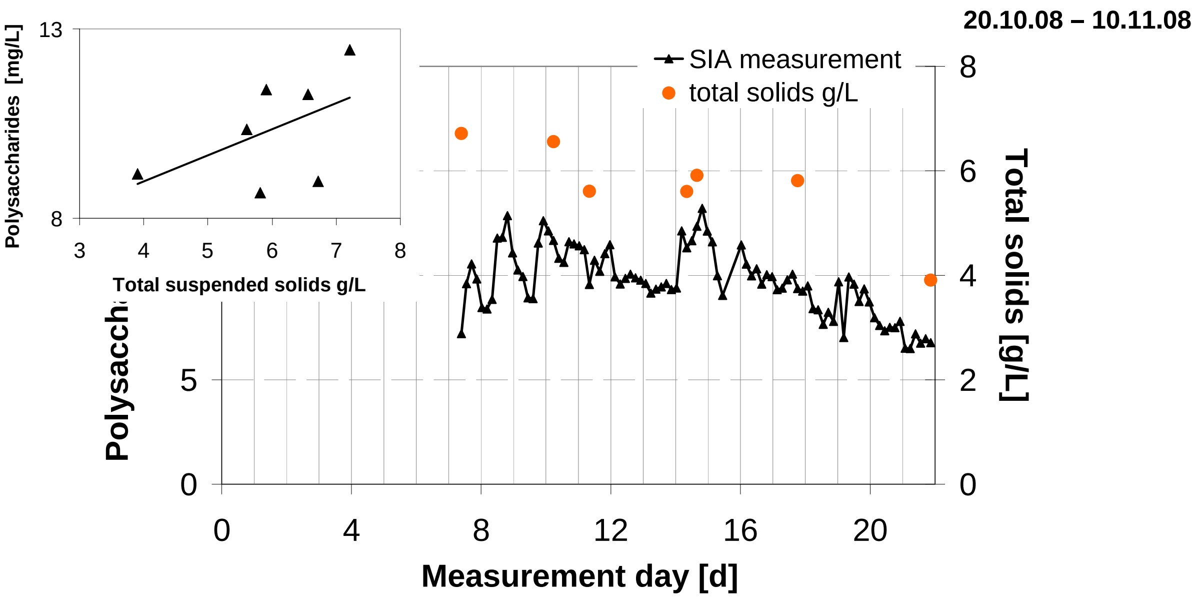
Sensor on the pilot plant

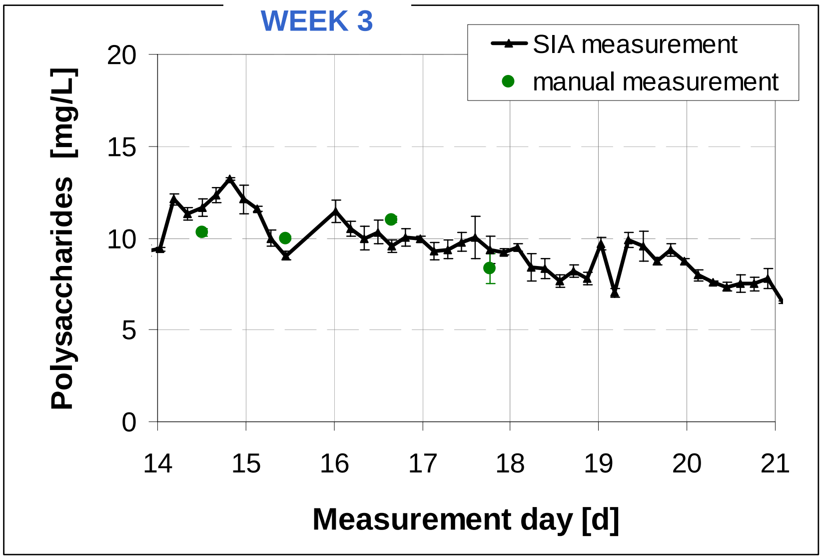


Polysaccharides – Pilot plant



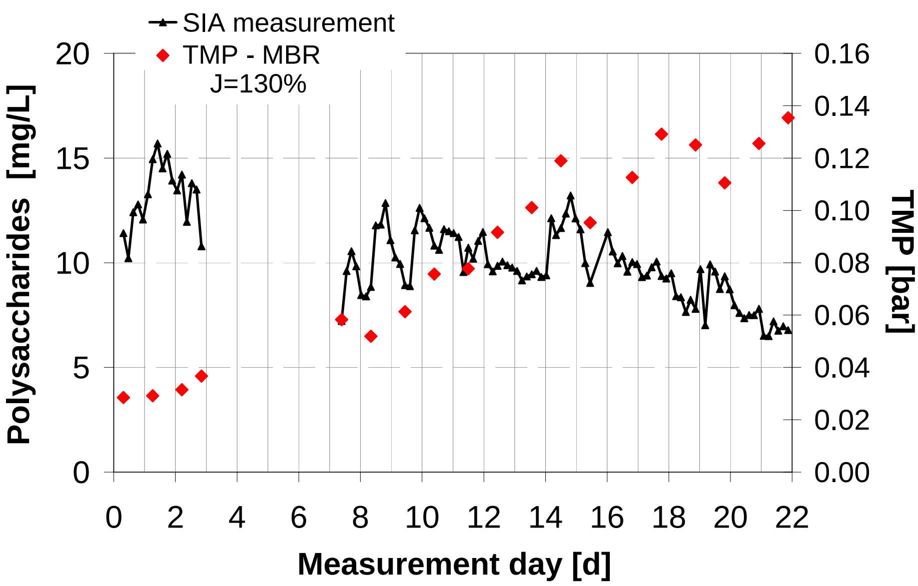
- High variation of PS during 3 weeks of operation
- Decrease of PS correlates with the concentration of TS

Polysaccharides – Daily variation



- **Daily PS fluctuation** (~1-2 mg/L during day)
  but no characteristic weekly profile of PS concentration visible

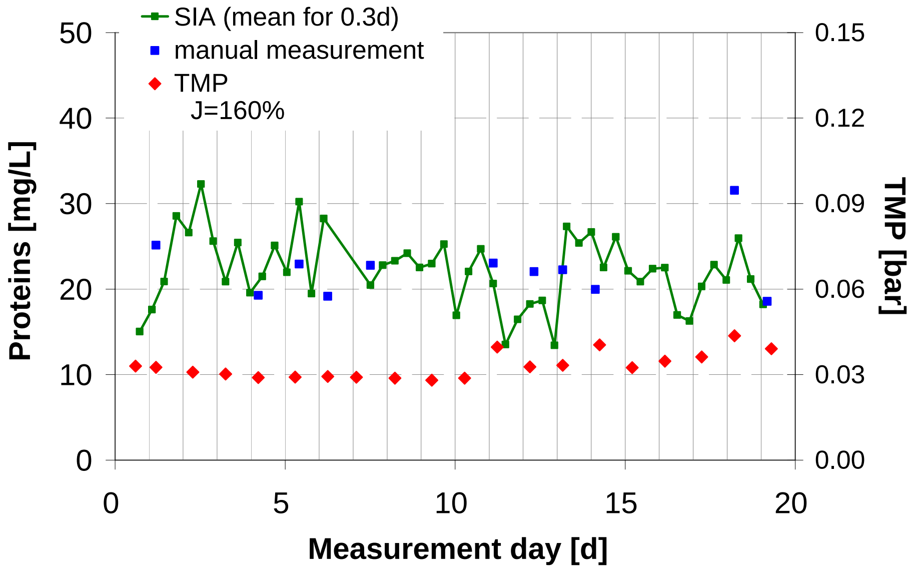
Polysaccharides versus TMP



- **TMP increases during the monitoring time but not PS**

Proteins – Pilot plant

13.11.08 – 02.12.08

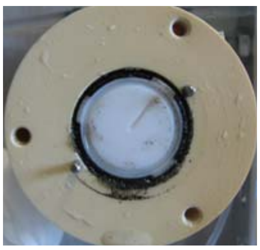


- **PR concentration as mean for 8 h**
- **Variation of PR between ~13–30 mg/L**
- **No trend can be observed**
- **Stable TMP**

Conclusions

On-line sensor for continuous photometric measurement of PS and PR was developed and tested in MBR pilot (Berlin, Mitte)

- **Automated method for PS** is suitable for monitoring in MBR
  - → low LOD, small measurement error and good robustness
  - → variation of PS can be recognised due to comprehensive data set
  - → Aggressive reagents (conc. H_2SO_4) requires caution and frequent maintenance



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Conclusions

- **Automated method for PR**
  - → monitoring of trends especially at high PR concentration (calculation of 8h mean)
  - → sensitive measurement in MBR limited due to relative high LOQ and measurement error
  - → **potential for method optimisation**

Currently no positive correlation of measured PS / PR vs. TMP

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Acknowledgement

AMEDEUS is a research project supported by the European Commission under the Sixth Framework Programme (Priority “Global Change and Ecosystems”)

Contract No. 018328 - AMEDEUS
Duration: 01/10/05 - 30/09/08
AMEDEUS is part of the MBR-NETWORK Cluster

More info: www.mbr-network.eu

7. THE EUROPEAN MBR TOUR OF THE DELFT FILTRATION CHARACTERISATION METHOD

J. H.J.M. van der Graaf, A. F. van Nieuwenhuijzen, S. Geilvoet, A. A. Moreau, M. Lousada Ferreira, P. Krzeminski

www.mbr-network.eu

The European MBR tour of the Delft Filtration Characterisation method

Jaap H.J.M. van der Graaf, Arjen F. van Nieuwenhijzen, Stefan Geilvoet, Adrien A. Moreau, Maria Lousada Ferreira, Pawel Krzeminski

(Final MBR-Network workshop, Berlin, 31st March 2009)

Content

- MBR sludge tour
- Delft Filtration Characterisation method
- comparison of MBR's
- sludge instability
- sludge concentration
- temperature
- filterability model

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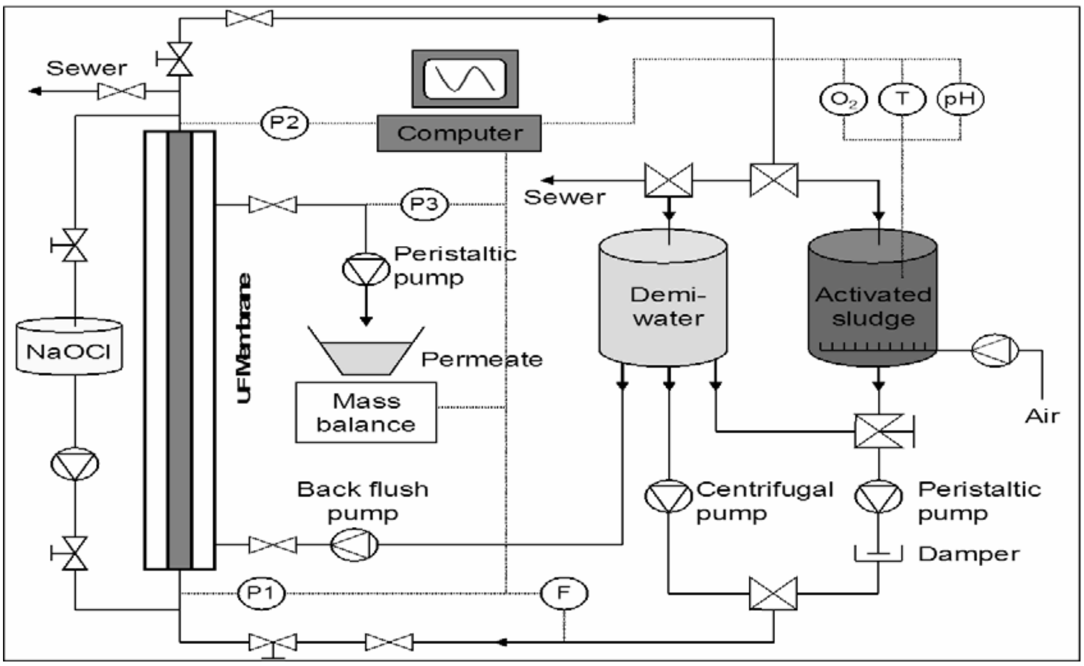
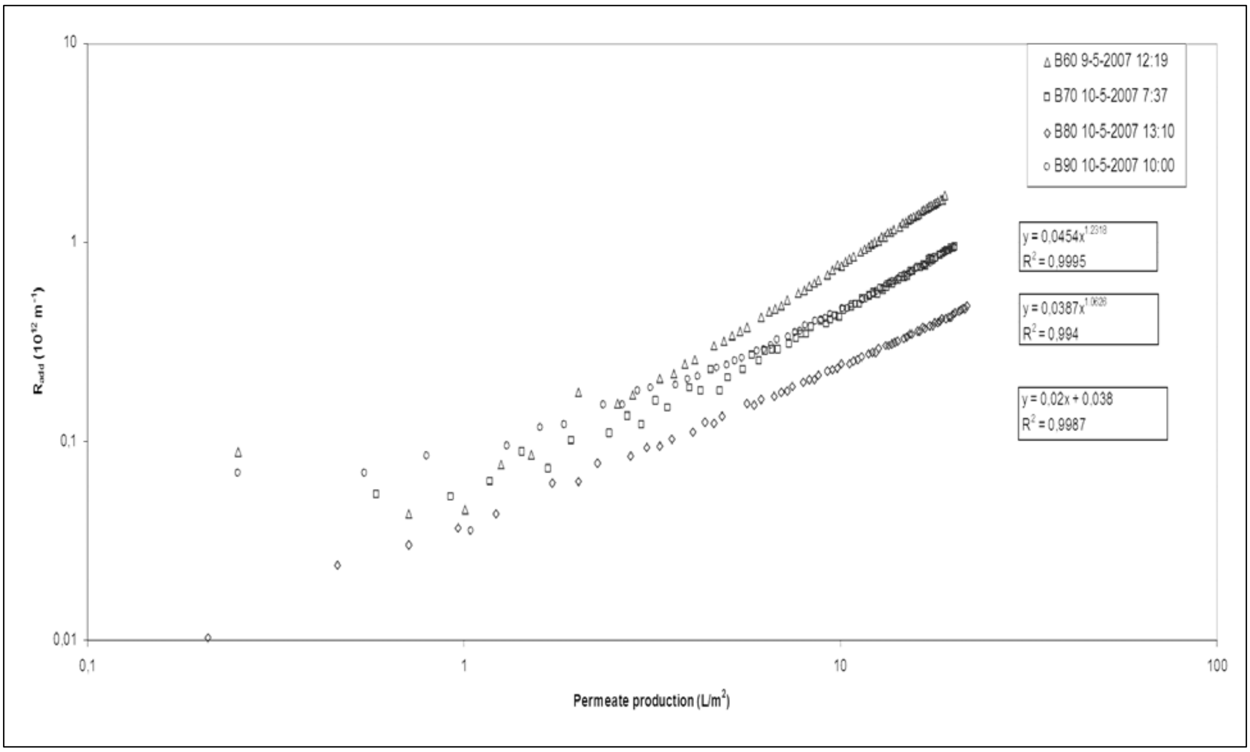
MBR test sites

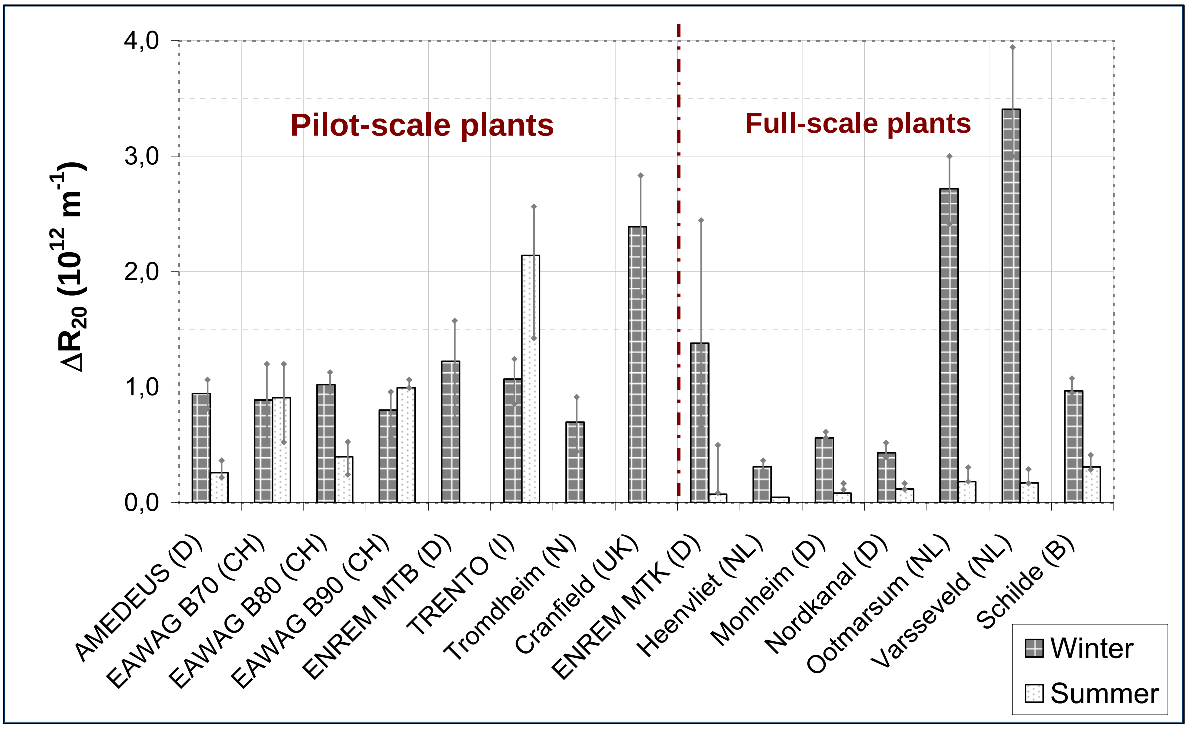
The Delft Filtration Characterisation installation



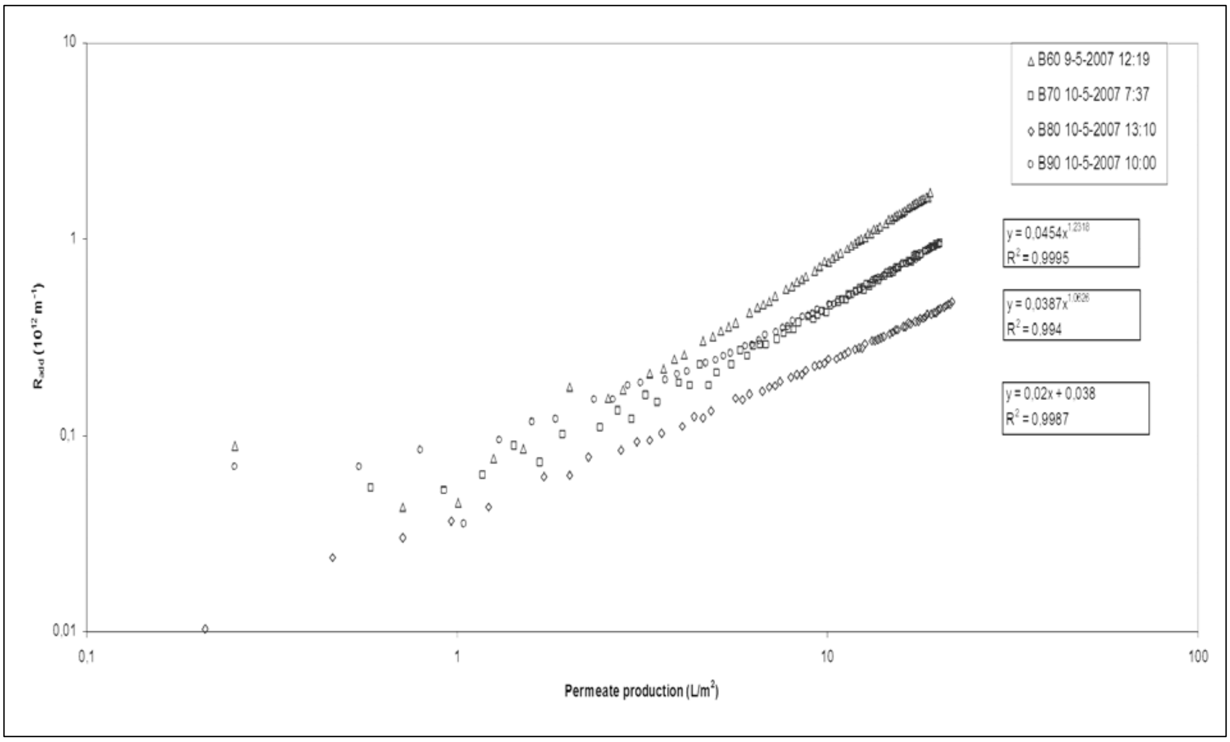
Filtration curves



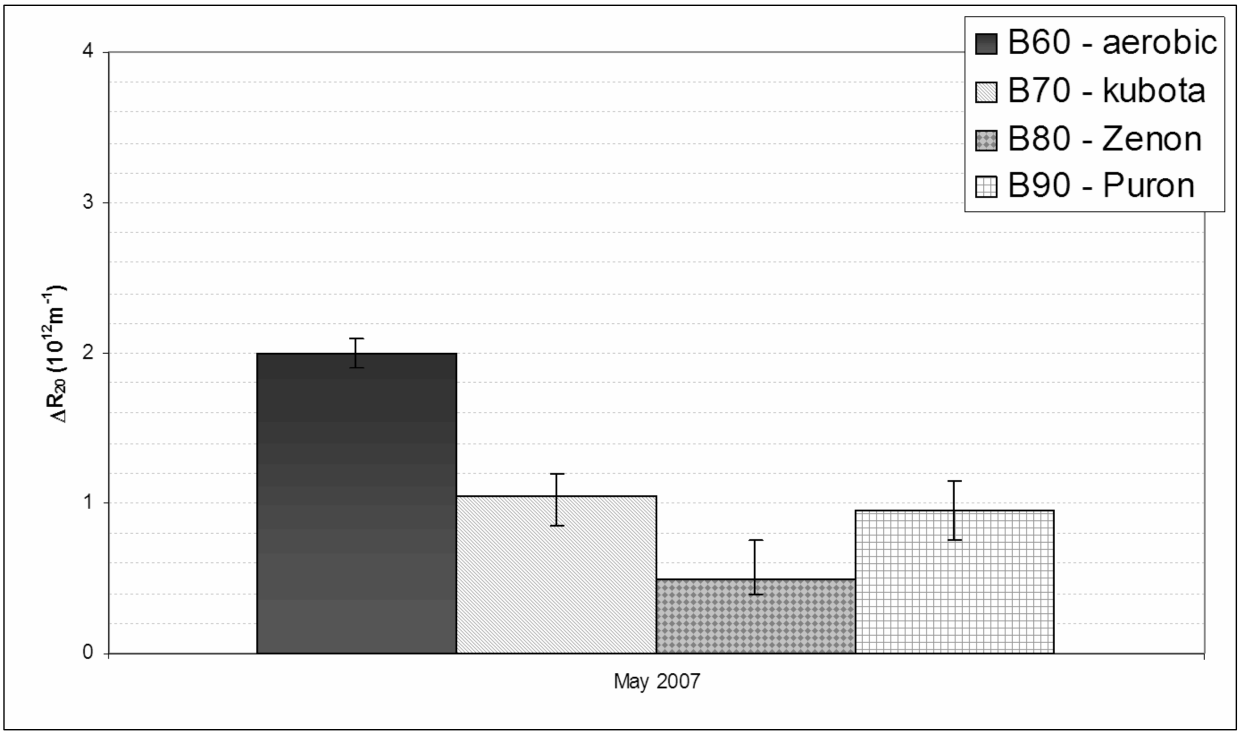
ΔR20 values for all the MBR sites



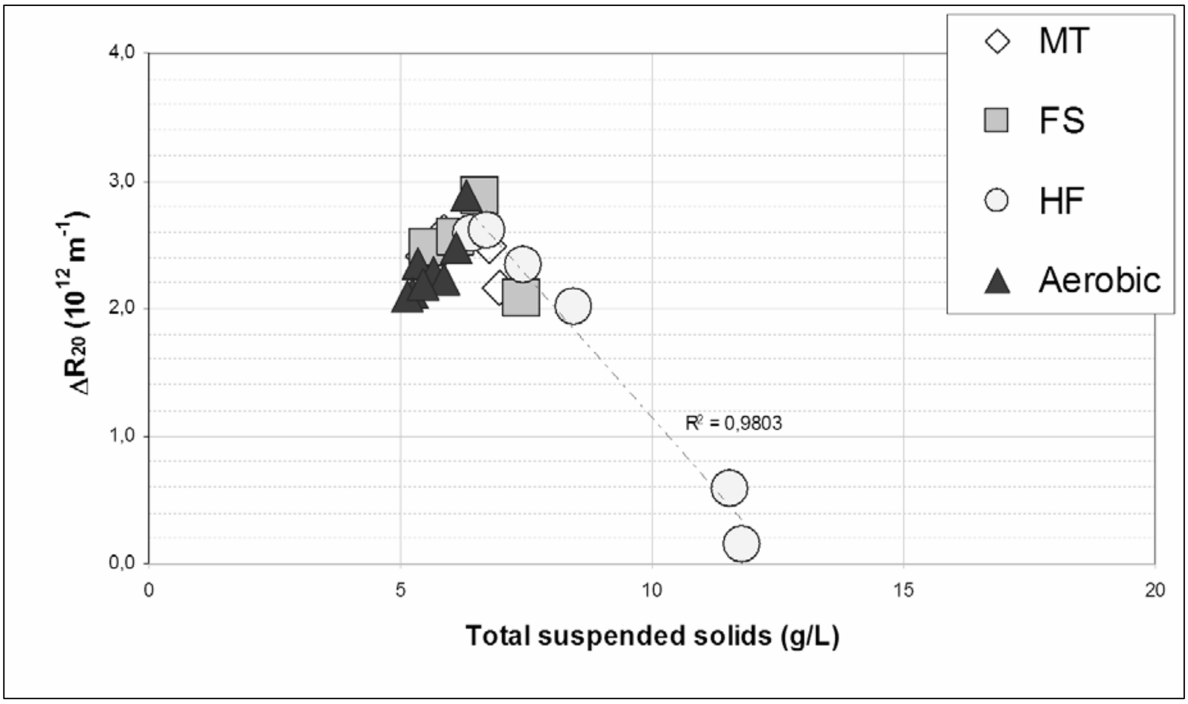
Eawag test site



Eawag test site



Influence of the sludge concentration (Cranfield site)



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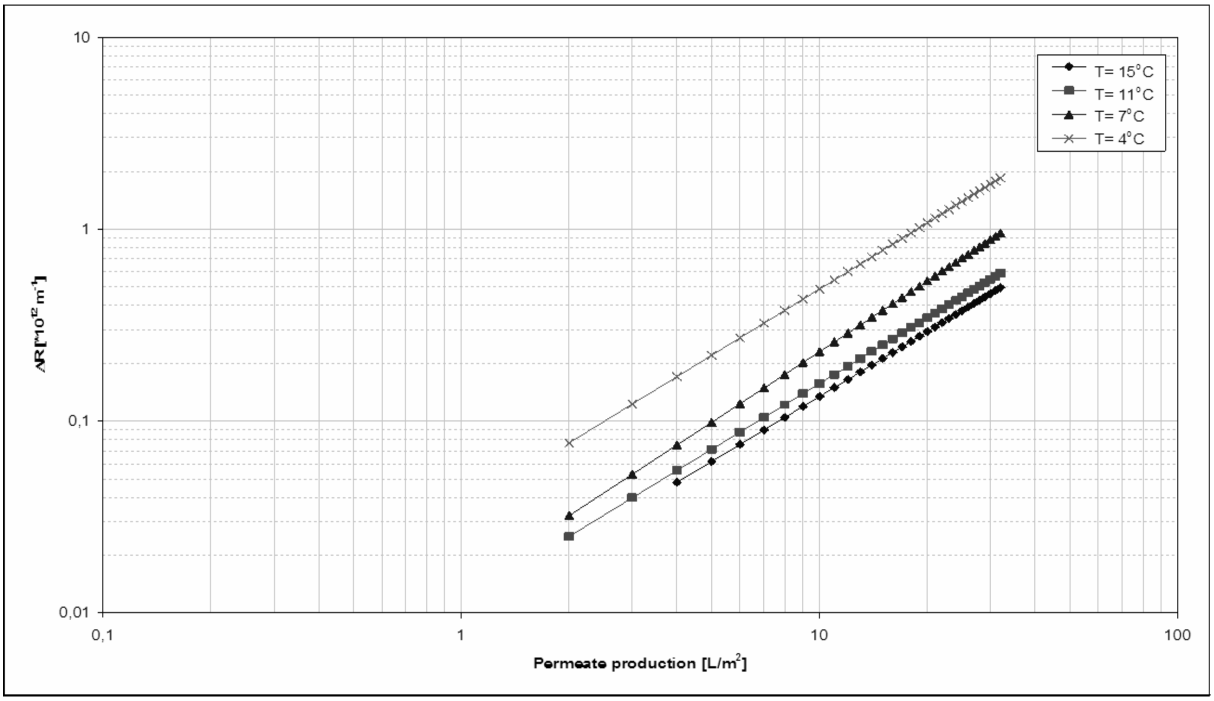
Change of temperature



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Filterability model

What is the reason for good or bad filtration characteristics?

- EPS?
- SMP?
- Proteins?
- Polysaccharides?
- …….?

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Filterabilty model

Strong relation between fiterabilty and

- submicron particles (0.1 - 1.0 µm) in the free-water phase
- total number => total volume / mass
- species => compressibility

- after negative temperature shock => increase SP
- higher temperatures => lower SP
- with high sludge conc (>10g/L) => decrease of SP
- sludge under stress => increase of SP

========> flocculation and deflocculation

Acknowledgement

EUROMBRA and MBR-TRAIN are research projects supported by the European Commission under the Sixth Framework Programme (Priority "Global Change and Ecosystems")

Contract No. 018480 - EUROMBRA

Duration: 01/10/05 – 31/05/09

EUROMBRA is part of the MBR-NETWORK Cluster

More info: www.mbr-network.eu

MARIE CURIE ACTIONS

8. THE QUEST FOR INDICATORS OF MEMBRANE FOULING IN MEMBRANE BIOREACTOR SYSTEMS

T. de la Torre, J. Stueber, V. Iversen, A. Drews, B. Lesjean

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The Quest for Indicators of Membrane Fouling in Membrane Bioreactor Systems

T. de la Torre*, V. Iversen, J. Stüber*, A. Drews**,***, B. Lesjean*, M. Kraume**, F. Meng****

*Berlin Centre of Competence for Water
**Technical University Berlin
***University of Oxford

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ENREM

KOMPETENZZENTRUM Wasser Berlin

MBR-TRAIN

Objective

- To find a universal indicator of fouling propensity of MBR sludge for plant operators
  - Easy
  - Quick
  - Cheap

How to find the fouling indicator?

Long-term monitoring campaign of several pilot to full scale MBR

- Measure filterability
- Measure parameters in activated sludge

→Find correlations

MBR units

INVESTIGATED MBR UNITS		SRT (d)	MLSS (approx.) (g/L)	Wastewater influent	Membrane	Reactor m³
Pilot plant	MBR1	12	9-10	Municipal	22 m² A3	1.5
	MBR2	12	7-13	Municipal	22 m² A3	1.5
Demonstration plant	MBR3	25	10-23	Domestic	31 m² A3	10
	MBR4	35	9-11	Domestic	20 m² Kubota	5

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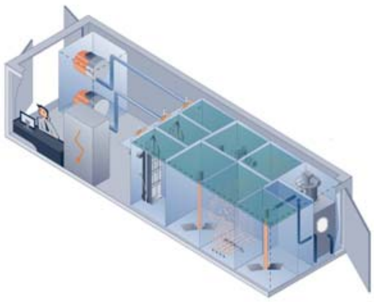

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Monitoring program

Monitored Parameters

- Quick-Filterability assessment:
  - Time to filter (TTF)
  - Capillary suction time (CST)
  - Sludge Volume Index (SVI)
- Bound and soluble EPS (SMP)
  - Polysaccharides
  - Proteins
  - Transparent exopolymer particles
- Temperature
- pH
- Nitrate
- Total solids
- Organic total solids
- COD….

On all 4 MBR units
2-4 samples / month
10 months campaign
Some parameters in fractions

- 10 µm
- 2 µm
- 0.2 µm

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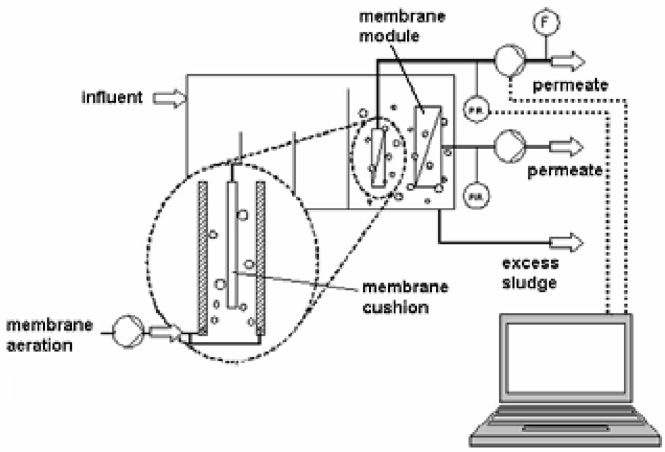
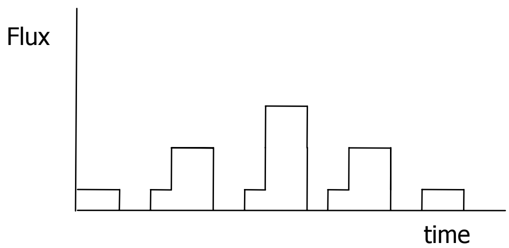
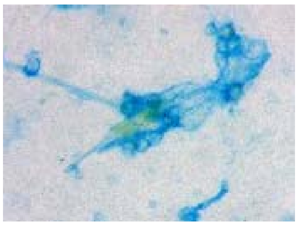
in-situ test cell BFM (Berlin Filtration Method)





- Critical flux measurements with standard protocol
- TMP Temperature corrected using $TMP_{corrected} = TMP^* \eta_{20°C} / \eta_{act}$

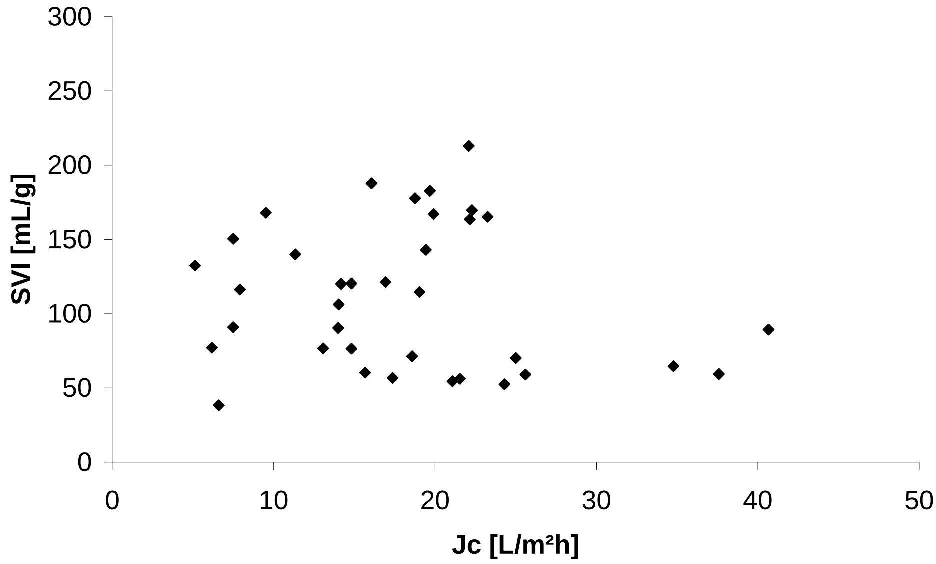
Transparent Exopolymer Particles (TEP)



- Mostly acid mucopolysaccharides = sticky polysaccharides (e.g. xanthan gum, alginate,..)
- Relationship with biofouling in RO (Berman and Holenberg, 2005)
- No study of TEP in wastewater treatment to date
- Easy to measure

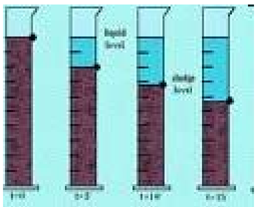
Results – Correlations against Jc
Univariable Analysis

Example Sludge Volume Index (SVI): no correlation at all



Results – Correlations against Jc
Univariable Analysis

- Other typical parameters…
  - TTF
  - CST
  - TS




→Only TTF was relevant for MBR3 (high TS and COD)

- No distinction between fractions (10 µm, 2 µm, 0.2 µm)

Results – Correlations against Jc
Univariable Analysis

- Best correlations against Jc:

bTEP/TEP	**r=0.84**
PS 2 µm	r=0.69
TEP rejection	r=0.68

- bTEP/TEP associated to flocculation-deflocculation proccesses
- The filterability of the activated sludge cannot be explained with one variable (no universal indicator)

Results – Correlations against Jc
Multivariable Analysis

Best fit for all units against Jc in situ
R^2 = 0.95

↑ bTEP ↑ T ↓TEP ↑ NO_3 → ↑ Jc

Parameter	Beta coefficient
NO_3	0.488
TEP	-0.596
T	0.566
bTEP	0.812

(relative influence of the parameter on Jc)

- NO_3 → important beyond its influence on SMP
- TEP → more importance than PS
- T → relevant even with T corrected Jc
- bTEP → favoures flocculation

Conclusions

- 95% of the variability of the Jc could be explained by the variation in 4 parameters in 4 MBR units for 10 months

bTEP	TEP
NO_3	T

Easy to monitor MBR plant operation

- TEP -->New important parameter introduced in wastewater investigations (fouling, flocculation,..)
- TTF and other "classical" parameters not so relevant

The filterability of activated sludge cannot be explained with one variable (no universal indicator)

.....But with 4!

MBR-TRAIN

Acknowledgement

MBR-TRAIN is a Marie Curie Host Fellowship for Early Stage Research Training supported by the European Commission under the 6th Framework Programme (Structuring the European Research Area - Marie Curie Actions)

Microdyn-Nadir - membrane supply

Berliner Wasser Betriebe – ENREM unit

Moritz, Guillem, Dhijan, Björn, Andrew, … for their work

Hauke and Bernardo for their help

MARIE CURIE ACTIONS

Contract No. MEST-CT-2005-021050

Duration: 01/01/06 - 31/12/09

MBR-TRAIN is part of the MBR-NETWORK Cluster

More info: www.mbr-network.eu and www.mbr-train.org

9. NEW DEVELOPMENTS IN MEMBRANE BIOREACTORS CHARACTERISATION AND MONITORING

C. F. Galinha, G. Carvalho, C. Portugal, R. Oliveira, M. T. B. Crespo, M. A. M. Reis, J. G. Crespo

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NEW DEVELOPMENTS IN MEMBRANE BIOREACTORS CHARACTERISATION AND MONITORING

Claudia F. Galinha, Gilda Carvalho, Ana F. Silva, Carla Portugal, Rui Oliveira, Maria T. B. Crespo, Maria A. M. Reis, João G. Crespo

FCT-Universidade Nova de Lisboa
IBET
Portugal

Membrane Bioreactor Characterisation and Monitoring

- Microbial Population Analysis
- 2D Fluorescence Monitoring
- Multivariate Statistical Analysis using Fluorescence Monitoring
- Hybrid Modelling Approaches

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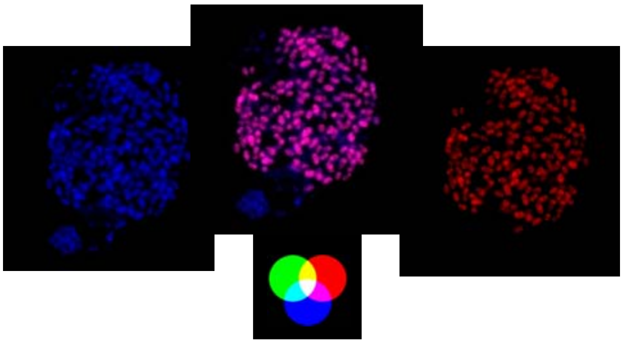
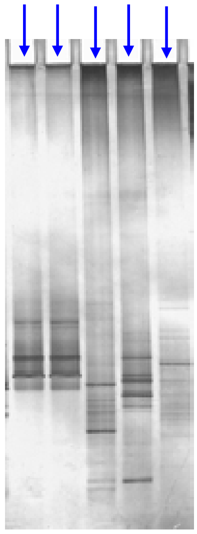
Microbial Population Analysis

- FISH (Fluorescence *in situ* hybridisation)
  - Analysis (quantification) of specific microbial groups





- DGGE (Denaturing gradient gel electrophoresis)
  - Profiling of microbial population structure
  - Diversity

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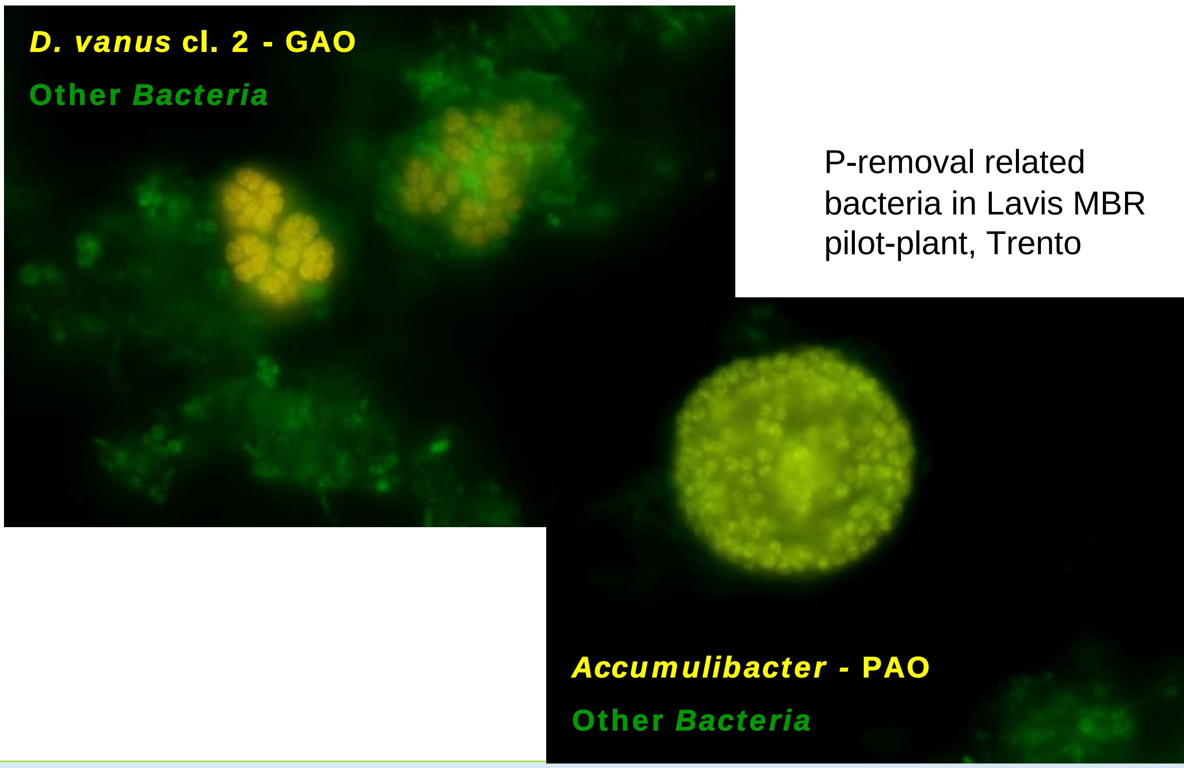
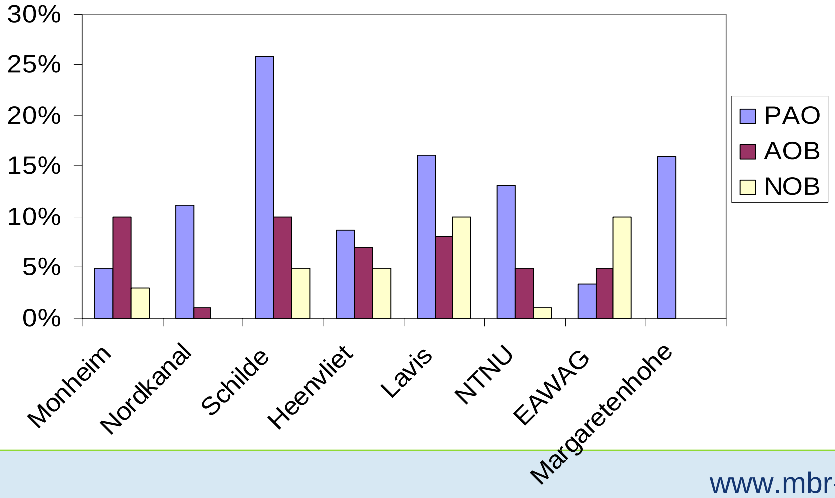
FISH Results



P-removal related bacteria in Lavis MBR pilot-plant, Trento

FISH Results

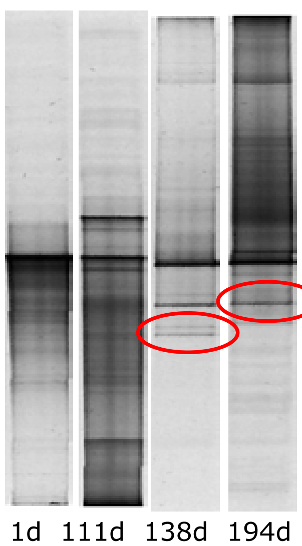
- Microbial community composition
  - General phylogenetic groups (*Alpha-, Beta-, Gamma-Proteobacteria*, etc.): **dominant phyla**
  - Specific bacterial populations (ammonia oxidising bacteria - AOB, polyphosphate accumulating organisms - PAO, etc.): **correlation with plant performance**



DGGE Results

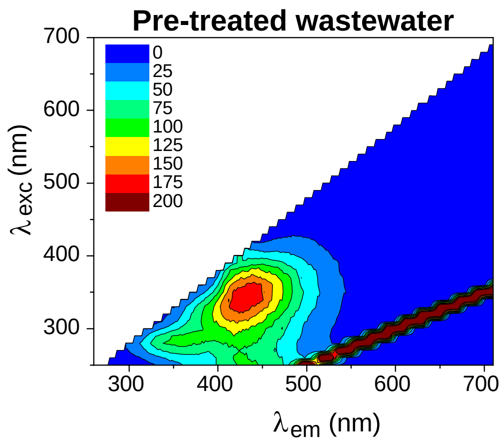
- Identification of changes occurring in a community

Operation conditions/ performance ↔ Population shifts ↔ Sequencing of bands



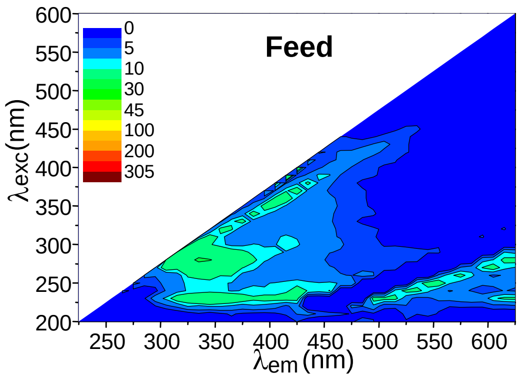
From band excising and sequencing it is possible to identify the corresponding bacteria

2D-Fluorescence Spectroscopy

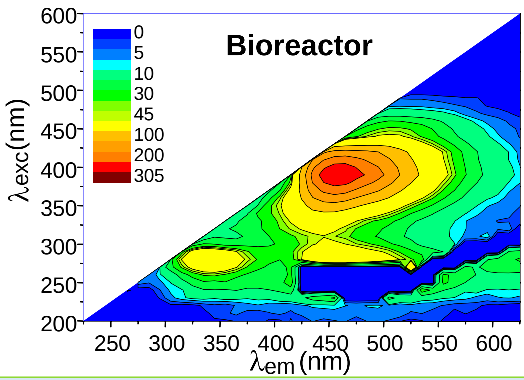


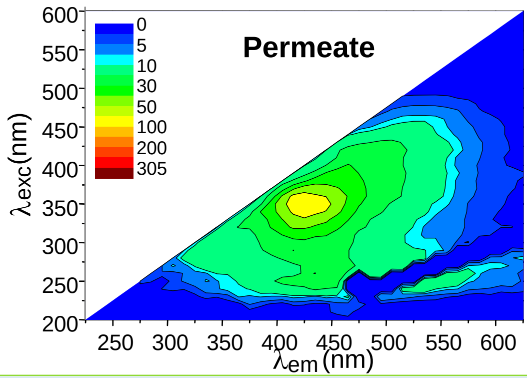
- Steady-state fluorescence
- Excitation wavelength, emission wavelength, intensity of emission
- Natural fluorophores: **proteins; some vitamins and cofactors**; substances with delocalised electrons such as **humic compounds**
- Quenching effects makes difficult a direct interpretation of fluorescence maps

2D-Fluorometry Monitoring of Membrane Bioreactors



Fluorescence fingerprints reflect different compositions of feed stream, bioreactor media and permeate





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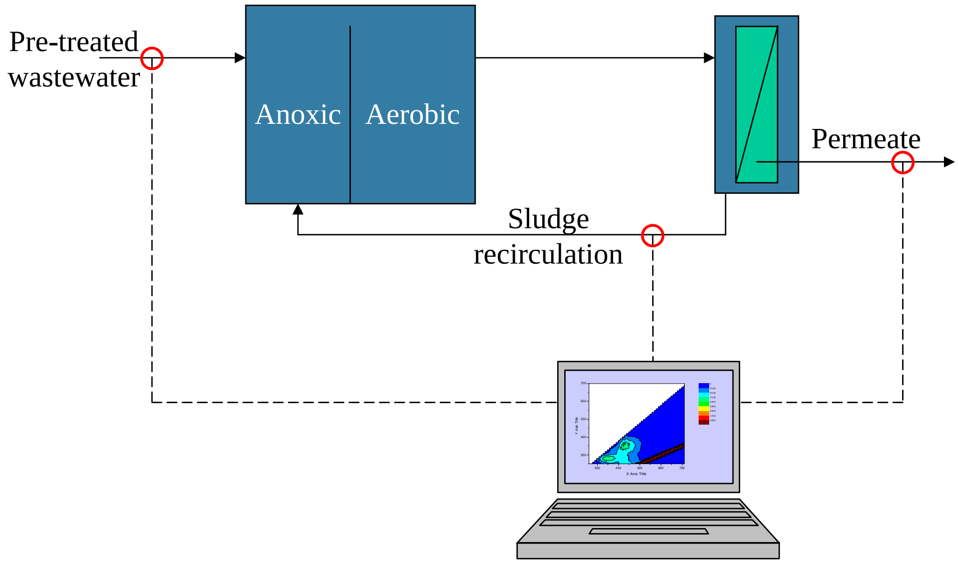
Experimental Setup

- Pilot MBR located in the Wastewater Treatment Plant of Lavis, Trento, Italy



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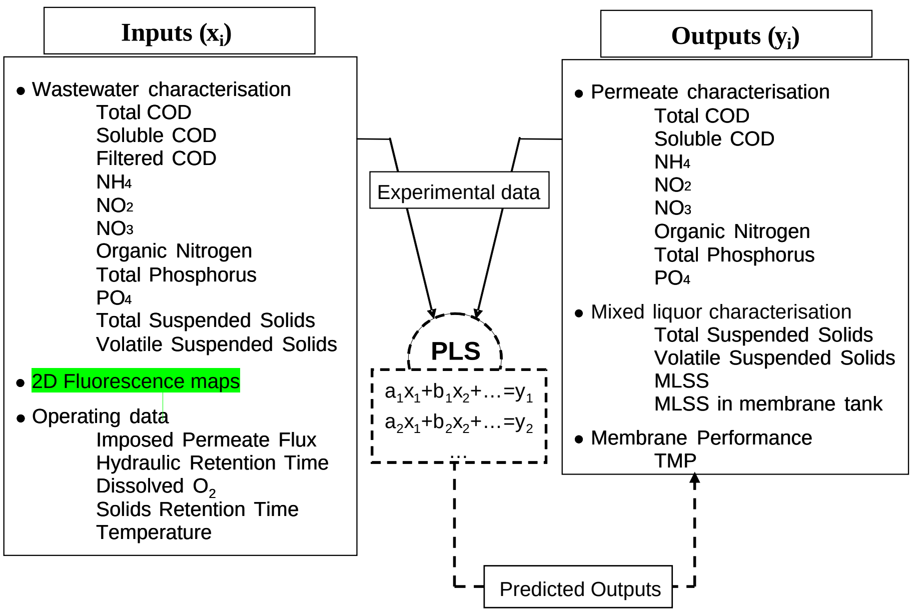
Development of Multivariate Statistical Models



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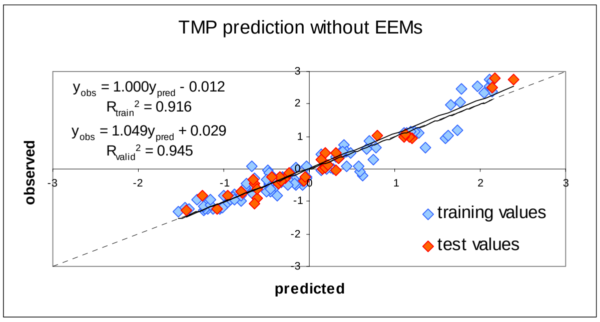
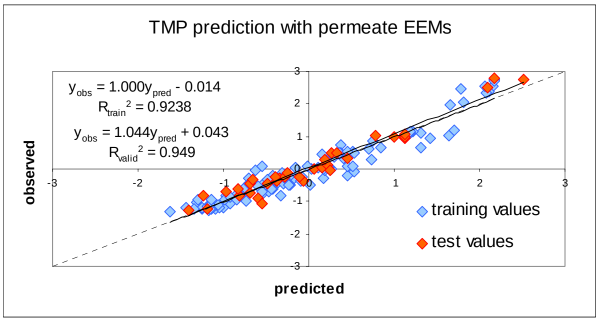
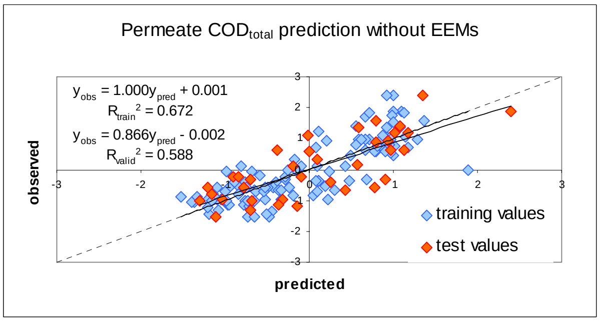
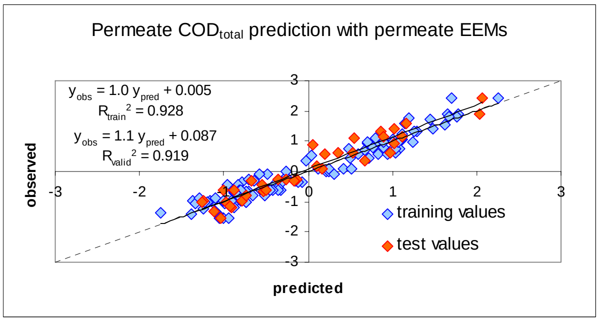
Modelling Results









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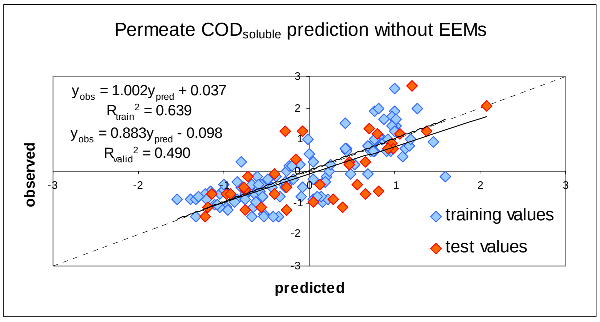
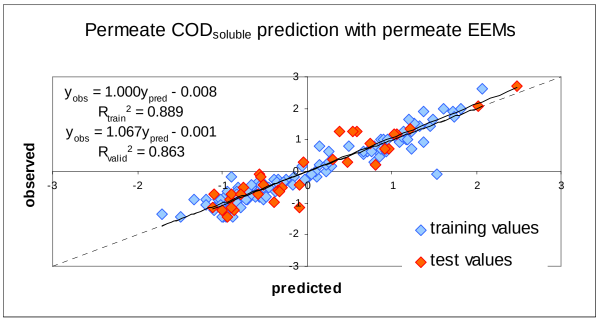
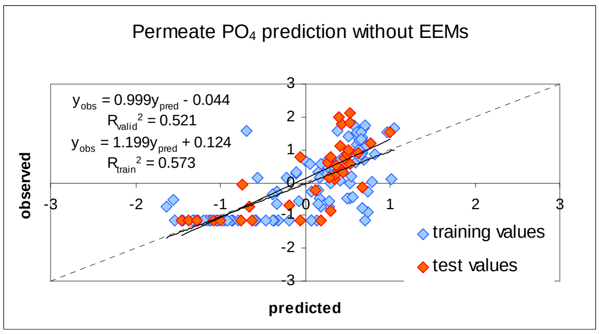
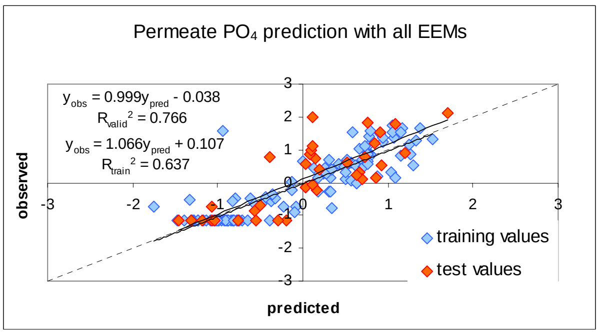
Modelling Results









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Integration of Information in Hybrid Models

Mechanistic knowledge

Other sources of knowledge…

Bioreactor characterisation data:

Spectra analysis

Image analysis

Modelling Challenges

1. Effective data mining
2. How to integrate different sources of knowledge in a model?

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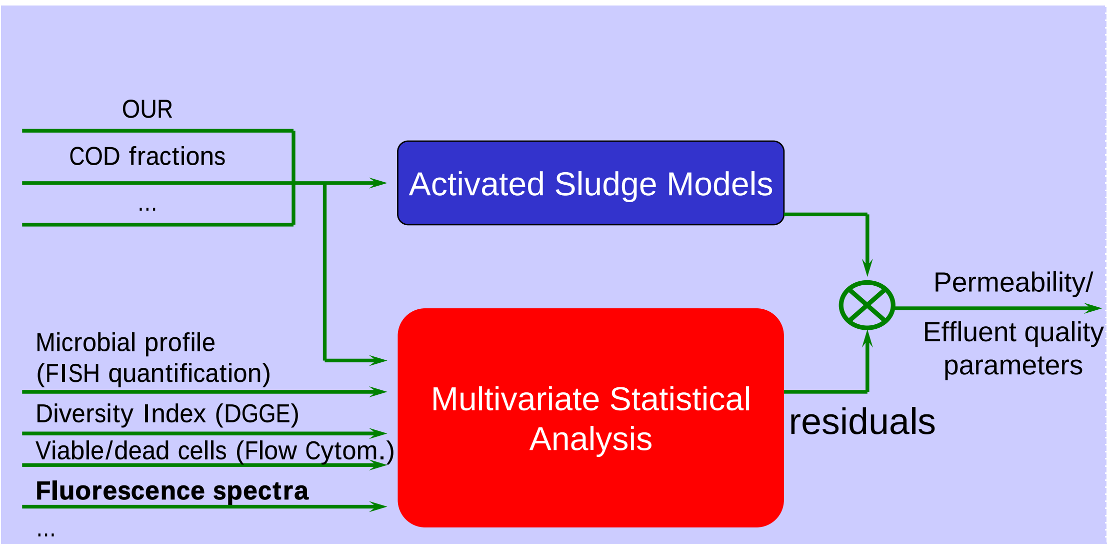
Hybrid Modelling Applied to MBRs



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Acknowledgement

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Contract No. 018480 - EUROMBRA

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EUROMBRA is part of the MBR-NETWORK Cluster

More info: www.mbr-network.eu

10. FOULANT DYNAMICS ON SUPPORTED MEDIA MEMBRANE BIOREACTOR

R. Aryal, S. Vigneswaran, J. Kandasamy, A. Grasmick

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FOULANT DYNAMICS ON SUPPORTED MEDIA MEMBRANE REACTOR

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NTNU Innovation and Creativity

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Introduction

CONTROLLING FOULING DURING MBR OPERATION REMAINS A CHALLENGE

Fouling due to biological conditions

- Unsteady operating conditions (flow input/HRT and organic loading)
- Sludge Retention time, F/M ratio (controls biomass characteristics)

Hydrodynamics Membrane and Module configuration

OBJECTIVES : Identification of
(i)means to control reversible fouling and minimise energy consumption and
(ii)Irreversible foulant materials in SMBR

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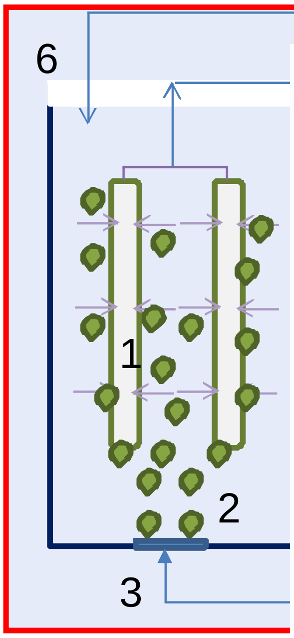
Part 1

Study on effect of aeration and support medium in membrane fouling (with kaolin clay suspension)



Reactor volume: 12 L

Membrane: Flat sheet module (mean pore size 0.14 µm)

Aeration rate: 1-4 $m^3.h^{-1}.m^{-2}$
Bubble size: 2-4 mm in diameter

Suspension of Kaolin :
- average particle size 4.1 µm

D[v, 0.1], D[v, 0.5] and D[v, 0.9] were 4.00, 4.46 and 5.10 µm, respectively
- particle concentration : 10 g/L

Procedure:
No relaxation and no backwashing
TMP measurement: Every 5 min interval (on line)

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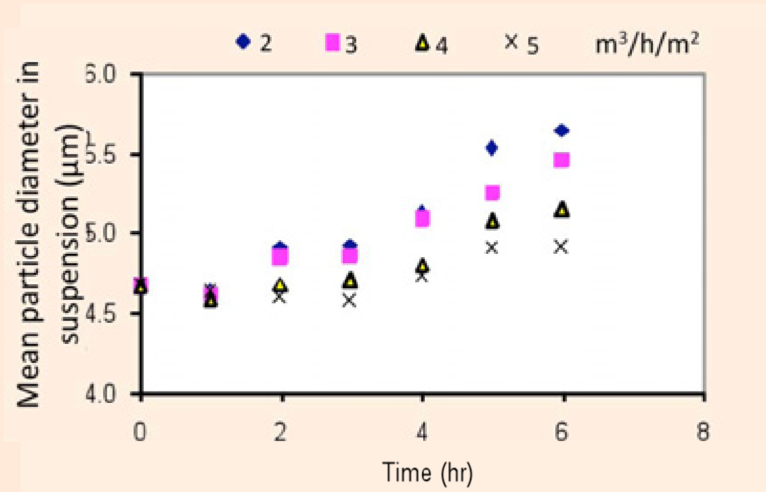
Effect of aeration on membrane fouling (TMP)

Increase of aeration decreased the fouling propensity
Reason: Aeration increases shear stress on membrane surface that helps scouring the surface



a

Low aeration favours fine particle deposit
Aeration increases mixing the suspension then both finer and coarser particles reach the membrane surface and heterogeneous deposition occurs.

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Effect of permeate flux on membrane fouling

Aeration rate of 2 $m^3h^{-1}m^{-2}$

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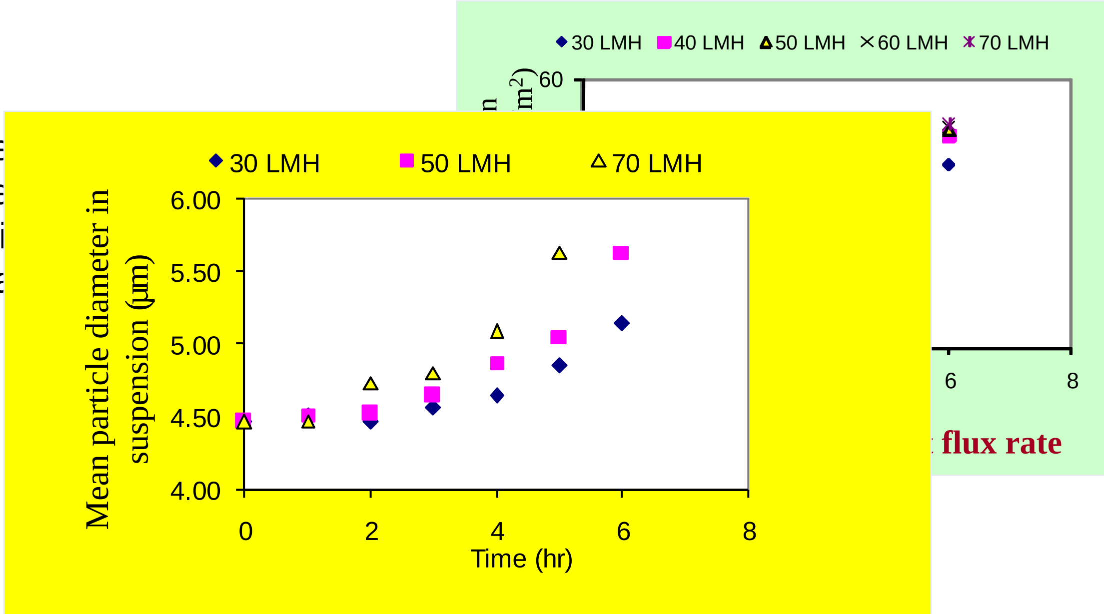

The smallest particles remain preferentially onto the membrane surface when increasing permeate flux

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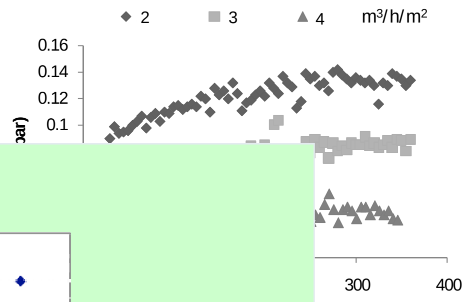
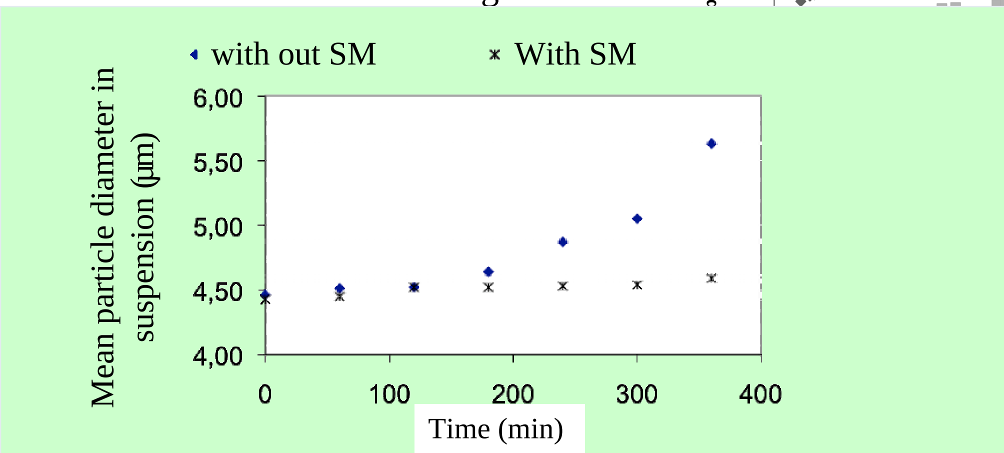
Effect of support media on membrane fouling (TMP)

Adding of 2 g/L Anthracite as support media (particle diameter >640 µm)

At all three different aeration rate found similar TMP rise reflecting support media has effective role in reducing cake de





Particle in suspension in absence and presence of support media

Aeration 3 $m^3/h/m^2$ and permeate flux 30 $l/m^2/h$

rt media

rt media

Support medium plays crucial role in scouring and mixing the suspension and thus allows a significant fouling reduction

Conclusion - Part 1
Study on effect of aeration and support medium in membrane fouling control

- Influence of shear stresses (air flow rate and support medium) and filtration intensity on deposit structuring and reversible fouling control

- Theoretical aspect :
  - Modelling with clay suspension and biological suspension

- **Practical aspects :**
  - **Nature of medium** **(size, density…)**
  - **Long term experimentation**
    - **Membrane life time and medium properties …**

Part 2
IDENTIFICATION OF IRREVERSIBLE FOULANTS IN MBR AND TEMPORAL VARIATION OF FOULANT CHARACTERISTICS

Parameters	Units	Periods	
		I (days0-22)	II (days 24-39)
Working volume	L	36	36
Organic load (Cv)	kg COD.m^{-3}.d^{-1}	0.9 to 3.0	1.5 to 3.0
Mean permeate flux	L.m^{-2}.h^{-1} (LMH)	5 to 20	10
TSS	g/L	1.8 to 4	4 - 5
Dissolved oxygen	mgO_2.L^{-1}	> 2	> 2
Membrane aeration	m^3/h.m^2 (L/h)	1.5 (300)	0.5 to 1.5 (100 to 300)

Membrane characteristics
PVDF – Pore size 0.14µm – Filtration area 0.2m^2
Number of sheets 8 - Gap between sheets 12mm
Specific surface 54m^2/m^3

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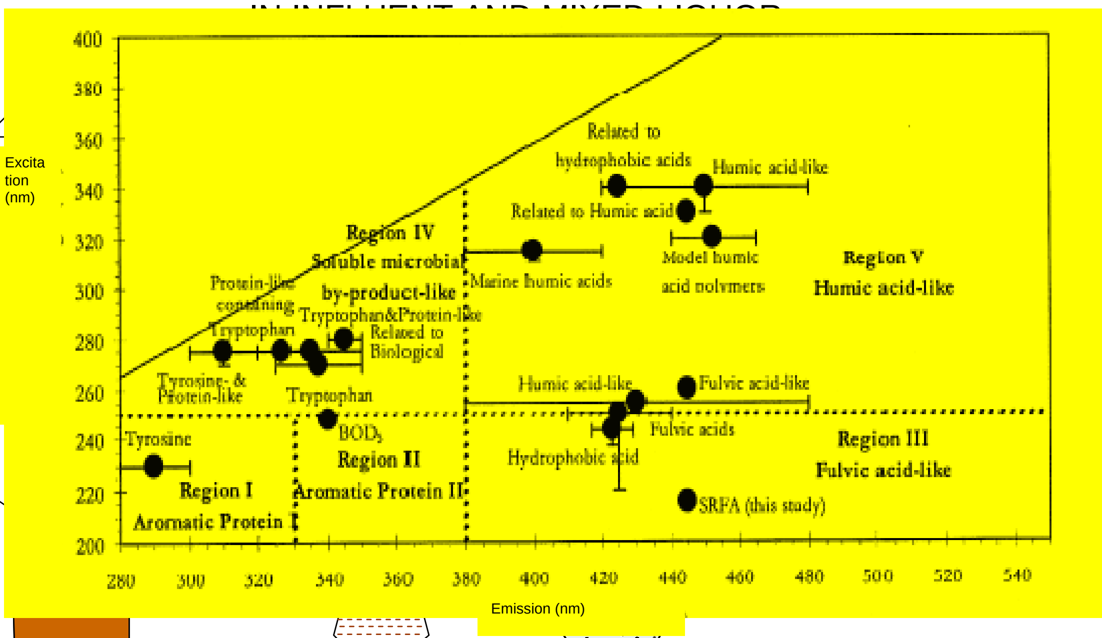
IDENTIFICATION OF SOLUBLE COMPOUNDS BY HPSEC (*High Performance Size Exclusion Chromatography)* AND EEM FLUORESCENCE SPECTROSCOPY



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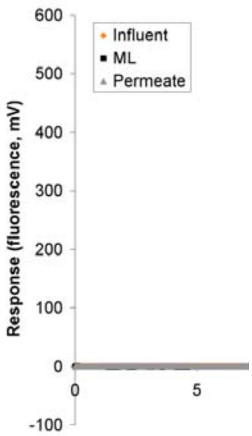
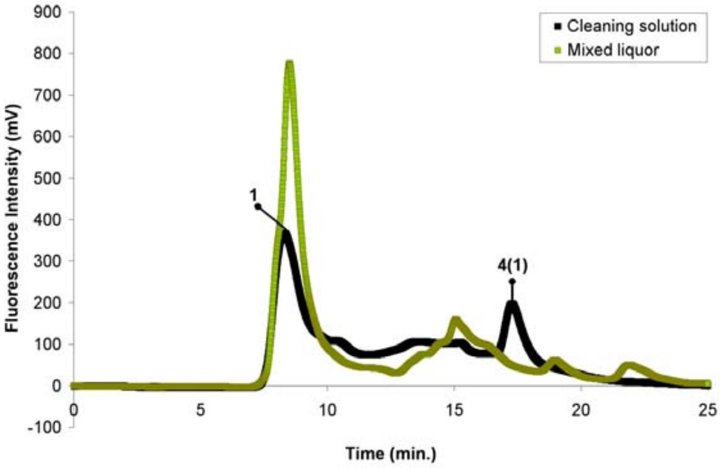
IDENTIFICATION OF SMP IN INFLUENT MIXED LIQUOR – PERMEATE



AND IN CLEANING SOLUTIONS



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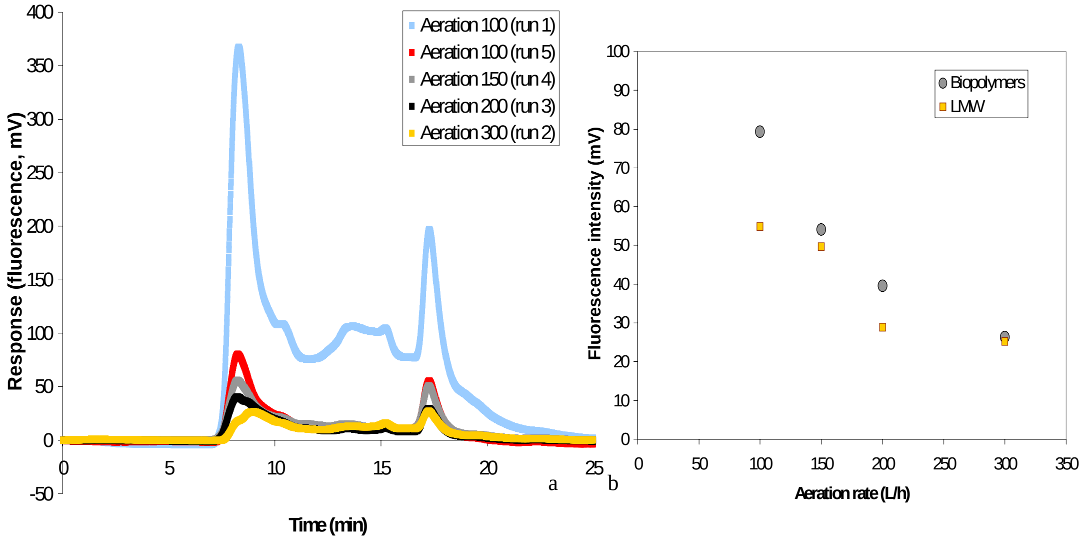
ROLE OF AERATION TO CONTROL SMP FIXATION

ANALYSES OF CLEANING SOLUTIONS



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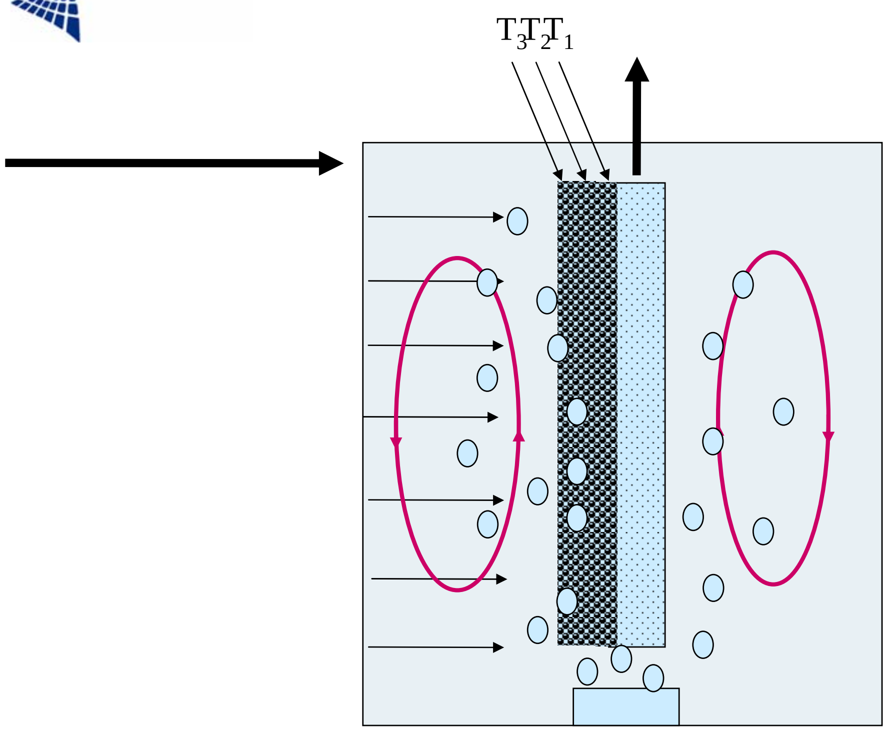
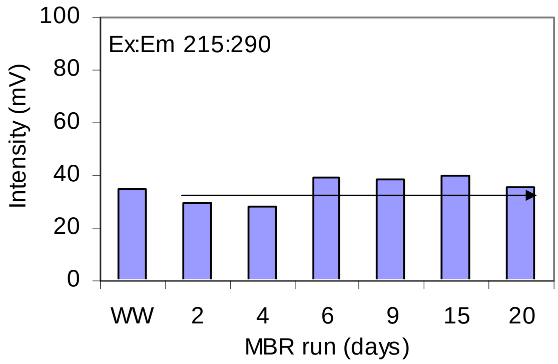
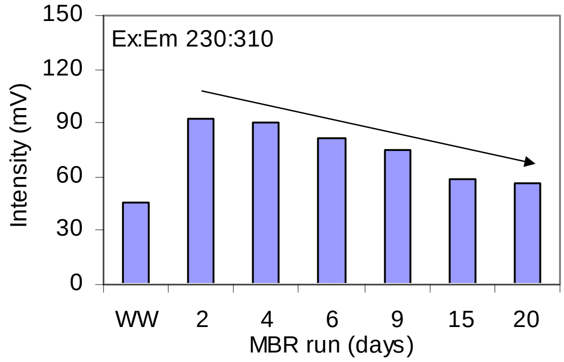


Target: Foulant Chemodynamics

Foulant composition with time





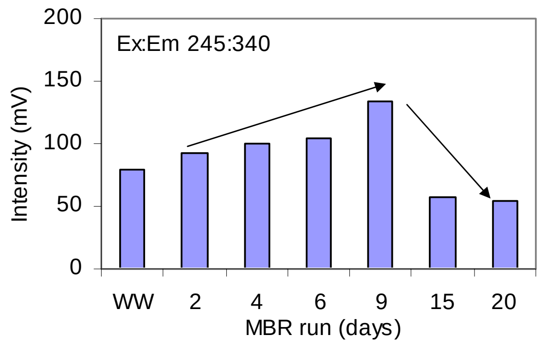
Low molecular weight substances including amino acids

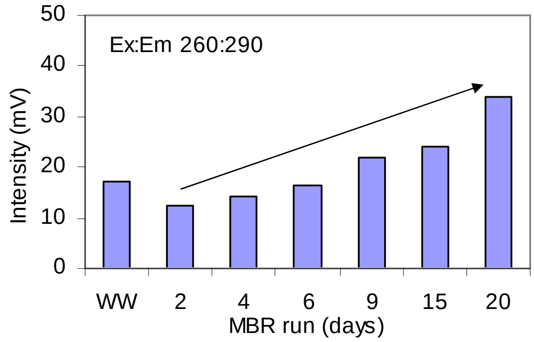
Remain unchanged in the foulant composition

Low molecular weight amino acids and aromatic proteins like substances

Relatively higher concentration during the early days and then decreased

Foulant composition with time





BOD5 type substances

Increase of bacterial activity in the beginning might have caused an increase of BOD5 substances in the foulant.

soluble microbial by-products

Foulant composition is more dominant with soluble microbial by-products with time.

Conclusion of part 2

- The organic foulants found onto the membrane surface appeared generated by the biological activity. They showed some changing of their ch

- Two … d for a longer … ulation of bipo … sludge accumu

- The … with a short du … 20 days of oper … version of low …

RELATION BETWEEN EVOLUTION OF BIOFILM COMPOSITION AND

-DRASTIC TMP EVOLUTION WITH TIME

-OPTIMISATION OF THE CLEANING STRATEGY

(HYDRAULIC AND CHEMICAL CLEANING)

Thank you for your attention and Acknowledgement

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More info: www.mbr-network.eu

11. ORGANIC MATTER IN MBR SLUDGE WATERS: FOULANT IDENTIFICATION AND CLEANING CONSIDERATIONS

A. Fenu, O. Braimah, J.W. Mulder, M. Kennedy, G. Amy

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Organic Matter in MBR Sludge Waters: Foulant Identification and Cleaning Considerations

Alessio Fenu*, Osi Braimah*, Jan-Willem Mulder*,
Maria Kennedy*, Gary Amy*
*UNESCO-IHE Institute for Water Education, Delft, The Netherlands
**Waterschap Hollandse Delta, Ridderkerk, The Netherlands

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Background

- Extracellular polymeric substances (EPS) /Soluble microbial products (SMP)
  - Hypothesized as membrane foulants in MBRs
  - Macromolecules (Proteins, Polysaccharides) & Organic Colloids
- MBR operating conditions (e.g., sludge retention time (SRT), mixed liquor suspended solids (MLSS), flux (J)) may affect:
  - EPS and SMP production and/or
  - Membrane permeability

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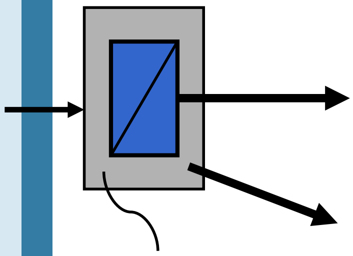
MBR Permeate versus Sludge Water Phase



Permeate Dissolved Substances

Activated Sludge ----> Sludge **Water Phase**

Paper Filtration:
Definition of SS
(~1.0 um)

MLSS

Colloids | Macromolecules

SMP/EPS

Discrete Separation Difficult

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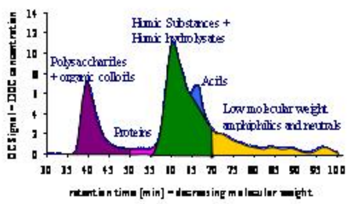
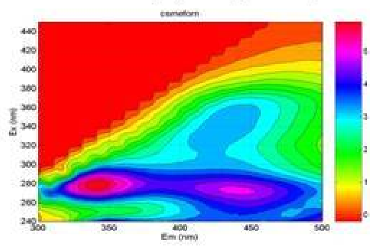
Foulant Measurements

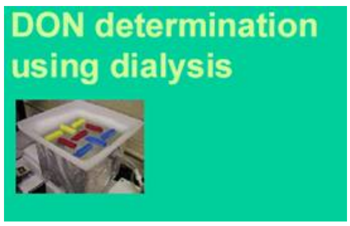
- Liquid Chromatography
  w/ Organic Carbon Detection (LC-OCD)
  - Separation According to Biopolymers (BP), Humic Substances (HS), and Low MW Acids (LMA)
  - ≈ LC-OCD (also, LC-OND, LC-UVD)



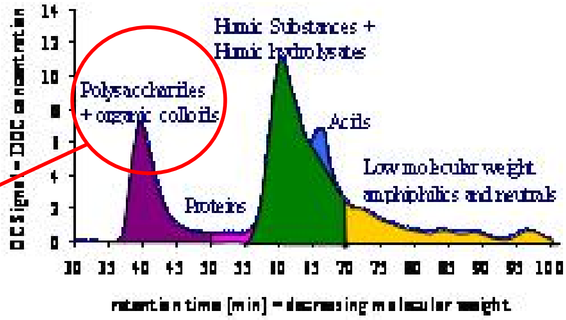
- 3-D Fluorescence Spectra
  - Excitation-Emission Matrices (F-EEMs)
  - Differentiate Protein- vs. Humic-Lake Materials
  - *Differential* Spectra (e.g., feed – permeate)



- Dissolved Organic Nitrogen (DON)
  - Separate Dissolved Inorganic Nitrogen (DIN) by Dialysis
  - *Direct* Measurement of DON by TN



Foulant Measurements



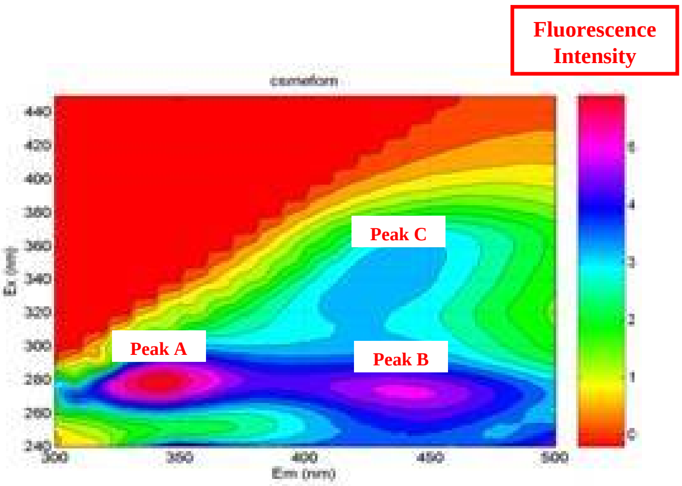
Biopolymers (proteins, polysaccharides)

Foulant Measurements

Peak A:
Protein-like peak ✓

Peak B:
(Primary) Humic-Like Peak

Peak C:
(Secondary) Humic-Like Peak



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Foulant Measurements

Proteins
(+ amino acids, amino sugars)

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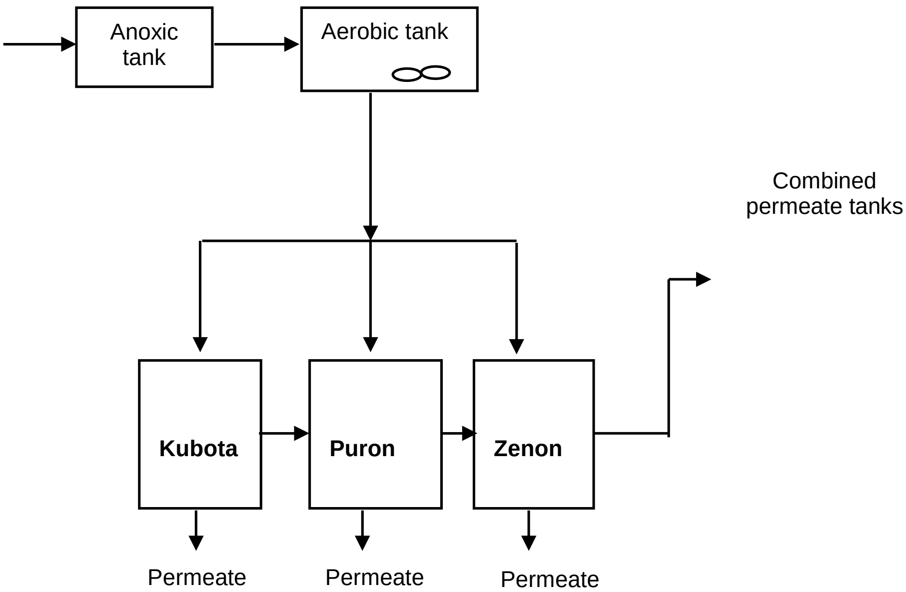
EAWAG Pilot MBRs (Joss, 2008)



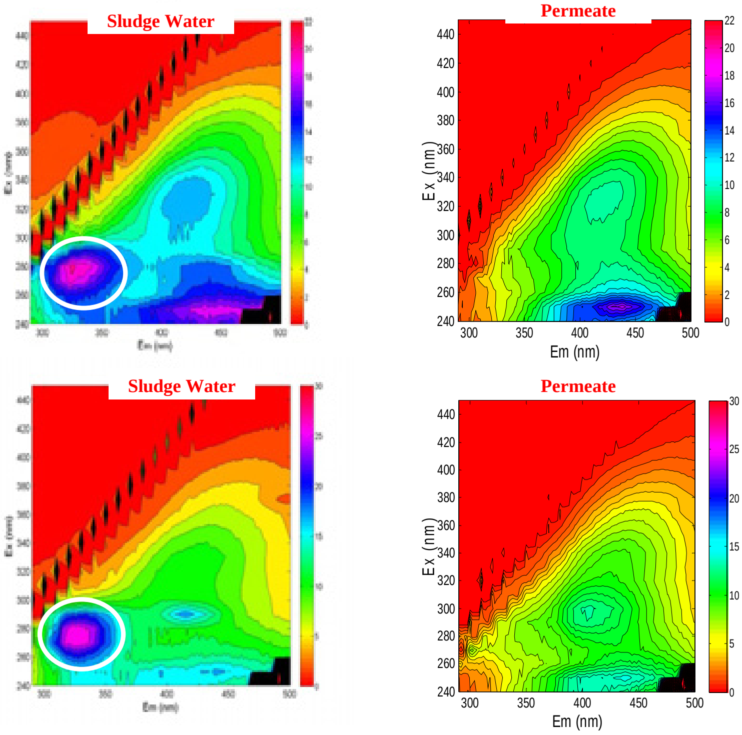
EAWAG Pilot MBRs (Joss, 2008)

MBR	EAWAG Switzerland		
Membrane type	Kubota FS	Puron HF	Zenon HF
Design capacity [p.e.]	100	100	100
Pore size [µm]	0.4	0.03	0.04
MLSS [g/L]	7.7-8.0	8-10	6-11
SRT [d]	10-14	7-8	8-10
Flux [LMH]	6.8-7.0	9-15	8.6-14.5
TMP [mbar]	502	336	110
Permeability [LMH/bar]	80-135	90-106	180-215

F-EEM Spectra: EAWAG Pilot MBRs (Puron, Zenon)

Puron membranes

Zenon membranes



Retentions **of Protein-Like and, to a lesser degree, Humic-Like: Fouling?**

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Fluorescence Intensities of Protein-Like Peak: EAWAG Pilot MBRs (Puron, Zenon)

Membrane	Fluorescence Intensity	
	Feed	Permeate
Kubota	30	25
Zenon	26	12

Pore Size: Kubota > Zenon

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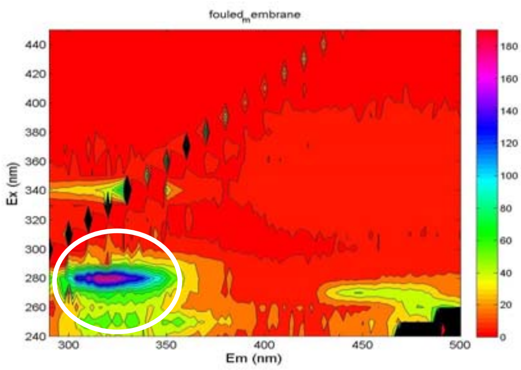
MBR Autopsy: Kubota Membrane

Fouled Kubota membrane:
24 hrs post chemical cleaning



F-EEM spectrum:
Extract from fouled Kubota membrane

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Application of Protocols to Samples from Operating MBRs

- MBRs
  - Arapahoe MBR
    - SRT = 19 days; HRT = 6 hours; MLSS = 11,100 mg/L
    - *Immersed* Zenon 0.02 um *UF*; Anoxic/Oxic
  - Georgia MBR
    - SRT = ? Days; HRT = 10 hours; MLSS = 3,360 mg/L
    - *Sidestream* Memcor 0.1 um *MF*; Aerobic
- Samples
  - Sludge Water
  - Permeate
- Testing
  - LC-OCD, F-EEM, and DON
  - Stirred Cell Simulations

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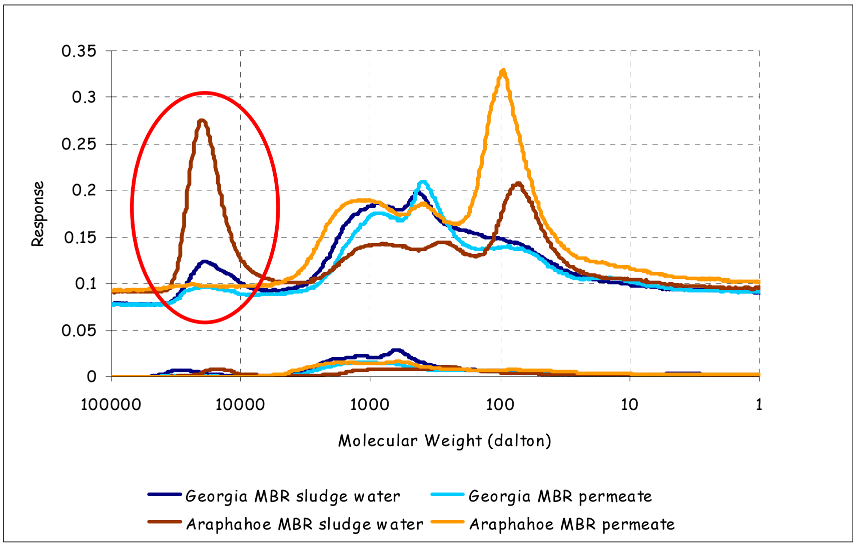
LC-OCD and DON: Sludge Water and Permeate



Biopolymer Peak:
ARM-MB = 4.5 mg/L
GEL-MB: 0.8 mg/L

Sample/ Parameter	Arapahoe MBR Sludge Water	Arapahoe MBR Permeate	Georgia MBR Sludge Water	Georgia MBR Permeate
DON (mg/L)	1.33	0.66	0.59	0.41

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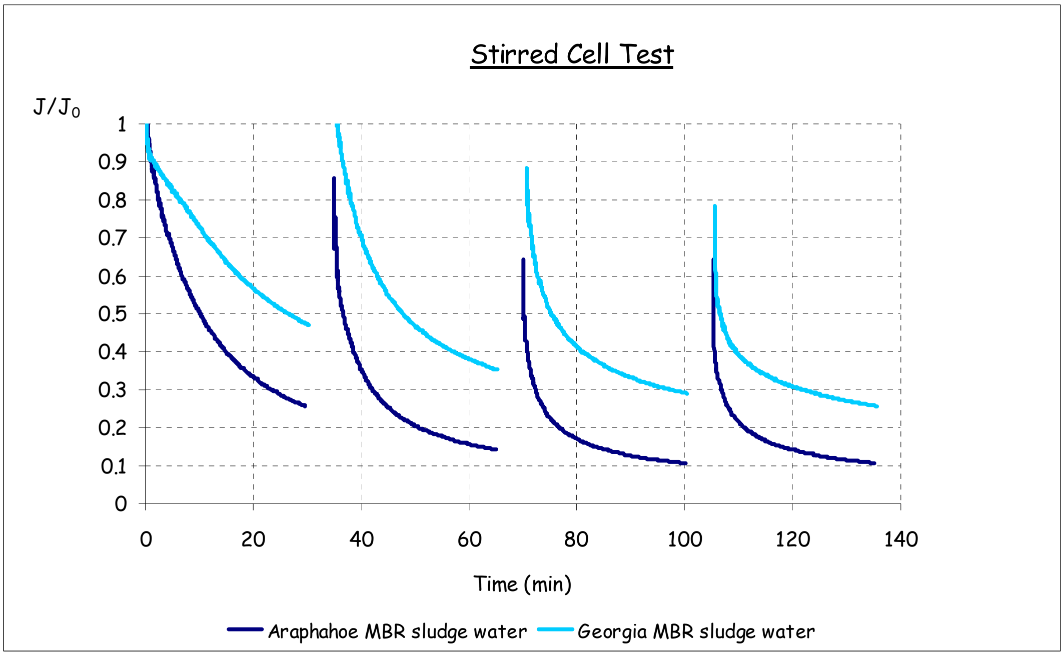
Stirred Cell Tests Results with Sludge Waters:
Normalized Flux vs. Time (min) + Simulated Backwashing



Hydraulically Irreversible Fouling: Arapahoe Sludge Water > Georgia Sludge Water

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Heenfliet MBR (Netherlands)

- Immersed Membrane
- Toray Flat Sheet Modules
  - 0.08 um PVDF
  - No hydraulic backwash
  - No maintenance cleaning
  - Low cleaning frequency (at time of study)
- Advised Toray Cleaning Protocol
  - Citric acid (max 3 %)
  - NaOCl (max 0.6 %)
  - Dosage by permeate pipes
  - Sludge remains in membrane tank

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  - Low cleaning frequency (at time of study)
- Advised Toray Cleaning Protocol
  - Citric acid (max 3 %)
  - NaOCl (max 0.6 %)
  - Dosage by permeate pipes
  - Sludge remains in membrane tank
  - High pH Hypochlorite (NaOH + NaOCl)?

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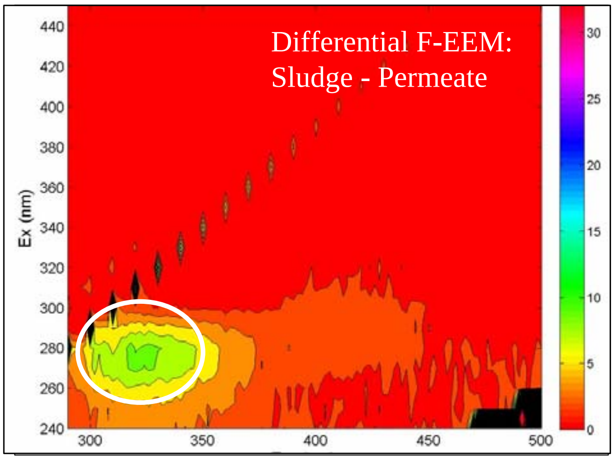
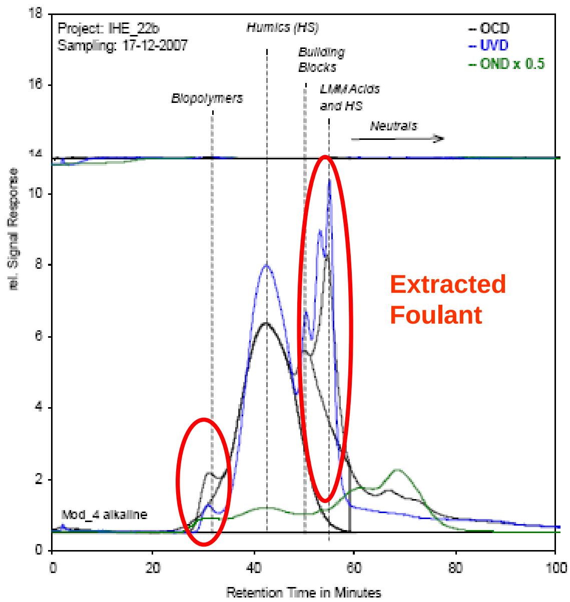
Characterization of Sludge Water and Extracted Organic Foulants





- Ratio of proteins to polysaccharides = 2:1 in biopolymer peak of sludge water (LC-OND and SUVA from LC-UVD)
- Protein and polysaccharide retention = 43% and 68%, respectively (colorimetric)
- Average retention of 5% for humics (F-EEM)

- Extracted by NaOH (pH 12) with sonication
- Protein hydrolysis?

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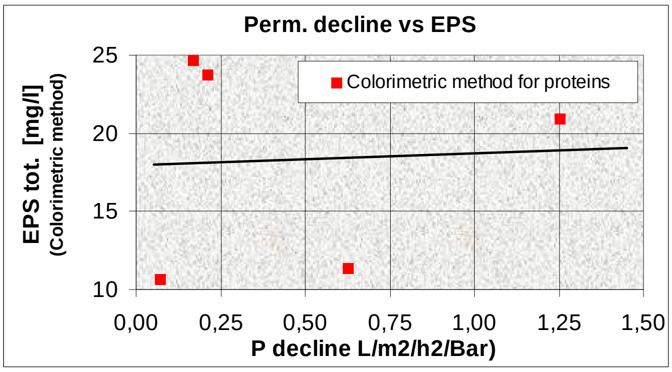
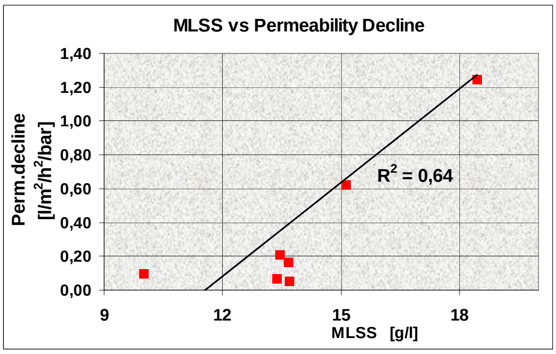
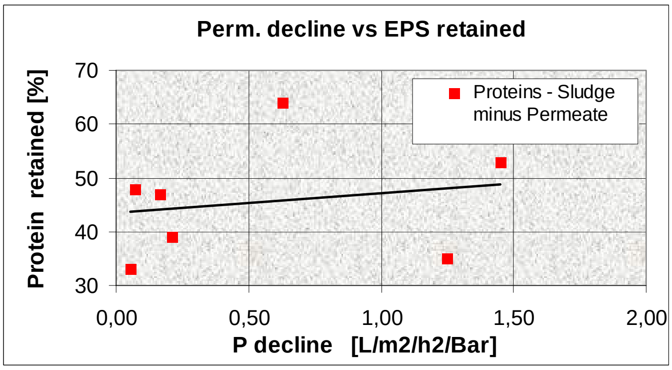
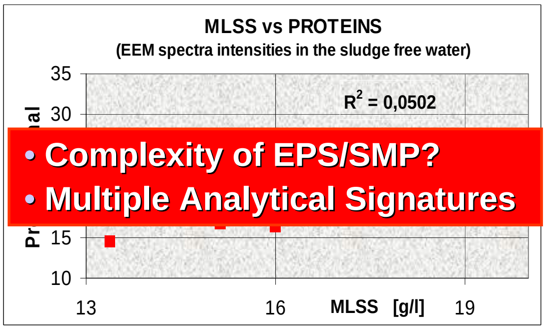
Correlations between permeability decline, EPS/SMP and MLSS









- Complexity of EPS/SMP?
- Multiple Analytical Signatures

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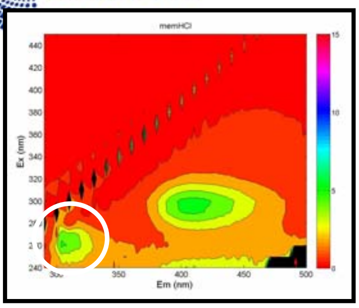

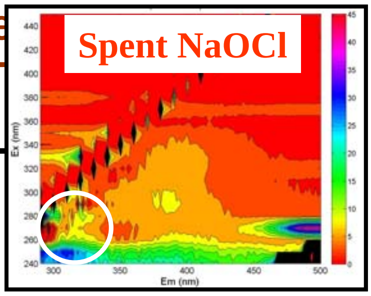

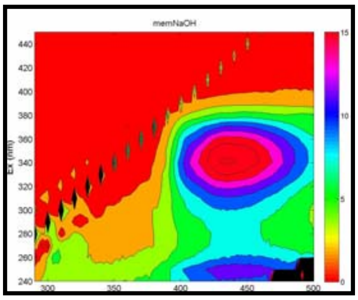

Acid cleaning (HCl)

Basic cleaning (NaOH)

ext:
feed
side

int:
permeate
side

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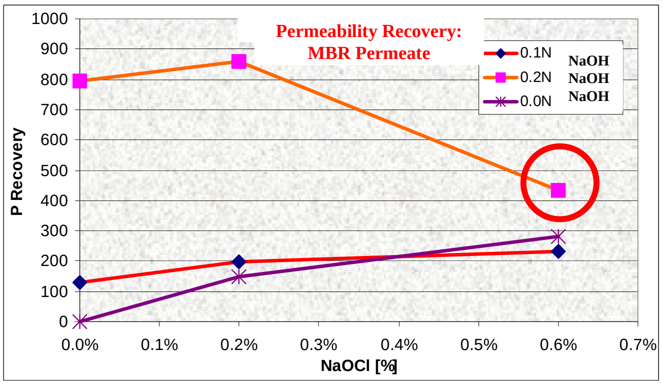
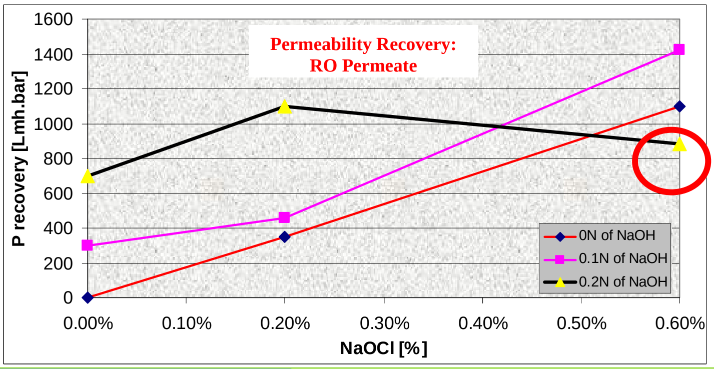
Bench-Scale MBR (Toray): Simultaneous Cleaning with NaOCl + NaOH from permeate side





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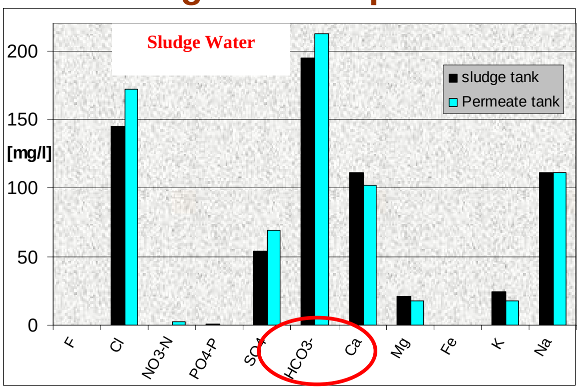
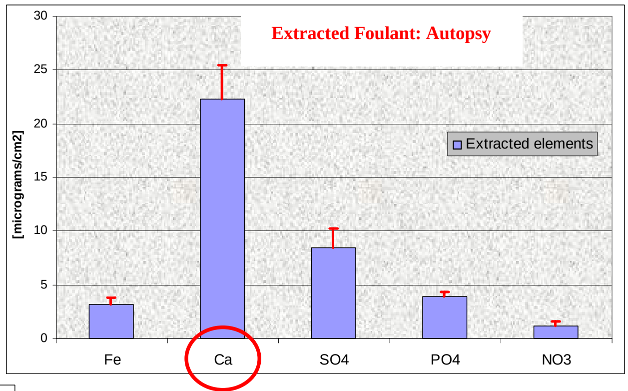
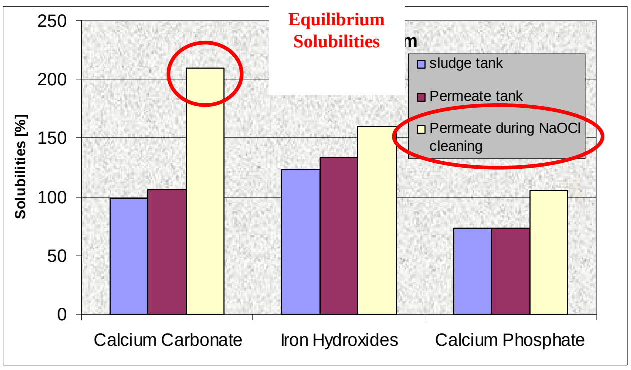
Bench-Scale MBR (Toray): Inorganic Composition of Sludge Water and Extracted Foulants







- SEM-EDX EDS measurements show that metals are mostly precipitated on the permeate side
- $CaCO_3$ represents 10% of foulants *on the permeate side*
- Separate NaOH and NaOCl steps

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Summary

- MBR membrane fouling is a complex phenomenon
- Analytical resolution of EPS/SMP (in sludge water, permeate, and extracted foulant) is possible but multiple techniques are necessary to fully reveal identity ⇨ LC-OCD + F-EEM
- EPS/SMP plays a role in MBR membrane fouling, with varying degrees of hydraulic reversibility/irreversibility
- Cleaning agents should be selected based on foulant identity; complexity of foulant generally necessitates multiple agents

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More info: www.mbr-network.eu

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