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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1. INTRODUCTIVE REMARKS

Roger Ben Aim

Final MBR-Network workshop

Introductive remarks

Roger Ben Aim

IWA Membrane Technology Group

IWA

- Drinking and Industrial water production (including desalination)
- Wastewater and sewage treatment including water reuse
- Sludge treatment
- About 6000 members
- Membrane Technology group : about 1300 members

MBR

- From the first events devoted to MBR (Cranfield 1995,Tokyo 1999) to this final MBR-Network Workshop.
- From the first patents 40 years ago to the first bubbling submerged MBR (20 years ago) to the huge research programs in Japan and then in Korea and Europe .

Some facts about MBR network

- In 2004: EC decide to support the development of the technology and open a call for tender
- Oct. 2005 – Jan. 2006: start of 4 EU projects fully dedicated to MBR development Amedeus, Eurombra, MBR-Train (Marie-Curie) and Puratreat (Inco project). The 4 projects will cluster under the coalition of projects "MBR-Network".
- Total budget of 16 M€ over 4 years (9 M€ from EU)

The importance of the research effort

- 50+ European and international partners (Australia, South-Africa)
- About 1.800 person-months = 150 person-years (~ 40 full-time p.a.) !
- => in average, each 15 min presentation in the workshop represents the equivalent of about 3 years of work for one engineer or PhD !!! (therefore very tight program)

MBR network Website

- MBR-Network edits also website dedicated to MBR technology:
  - Already 1000 international individual members, and about 150 corporate members
  - Reports of EU project
  - Monthly literature scan: database of about 1200 references
  - Discussion / information forum

MBR

- Equivalent population treated by MBR to day: about 10 millions (roughly estimated!) much less than the annual growth of the World population!

- Growth rate of MBR technology : about 25% , more than any other membrane process (including RO)

Important potential market for MBR

- Depending on regulation (discharge in surface water, water reuse)

- Depending on economic factors (pricing of treated water)

Bellagio statement

- The future of MBR linked with a new vision of more sustainable water management .
- New paradigm : from centralized management to more decentralized

In conclusion

- Considerable progress : much better understanding, more robust technology
- Some new questions
  - Micropollutants ,…
  - Accessibility to developing countries
- A decisive step but hopefully we are still far from the inflexion point of the Scurve:
  - dissemination of the results for geographical extension
  - Technical issues (standardization?)

Big Thanks to Boris and TorOve!

2. EUROPEAN STRATEGY AND ACTIVITIES RELATED TO MEMBRANE AND WATER RESEARCH

Andrea Tilche and Michel Schouppe

EUROPEAN COMMISSION
European Research Area

European strategy and activities related to membrane and water research

MBR-Network final workshop, Berlin (DE), 31/03/2009

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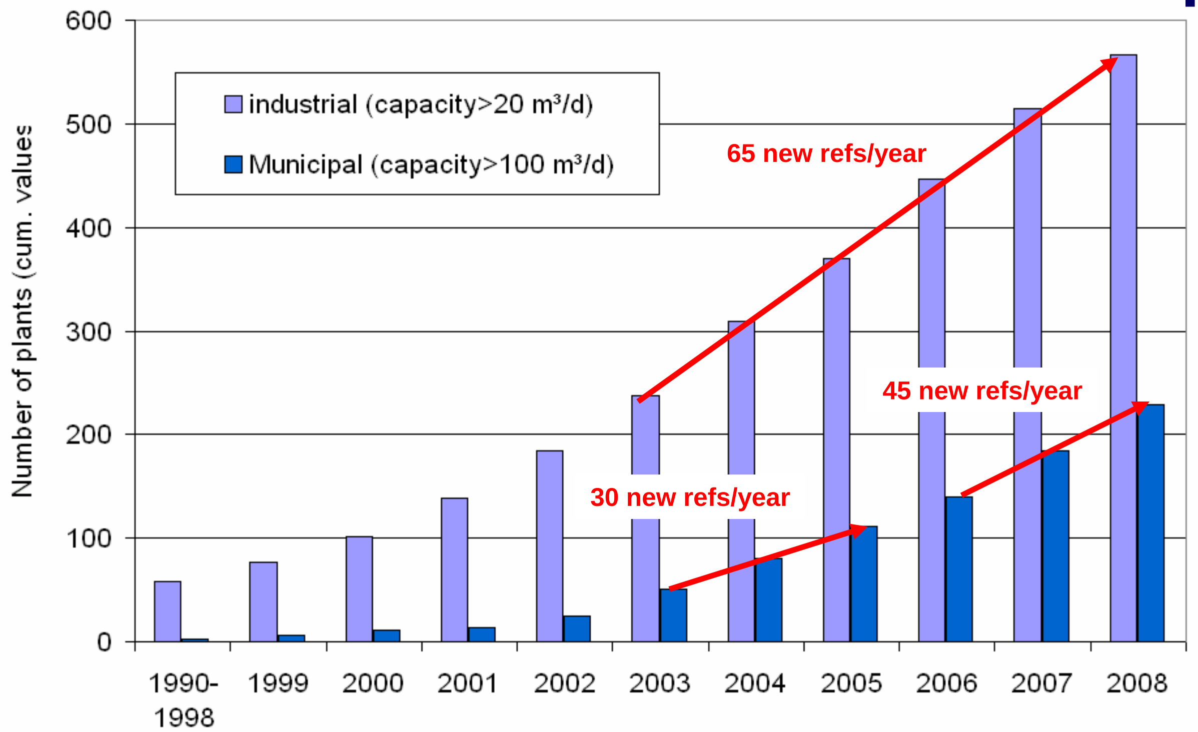
EUROPEAN COMMISSION
European Research Area

The MBR-Network

- Successful example of cooperation
- Formalised links between four individual projects
- 50 partners initiating an international network of 1000 members
- Increased visibility, leveraged outreach
- **__Common aim__: MBR as a common competitive treatment alternative**

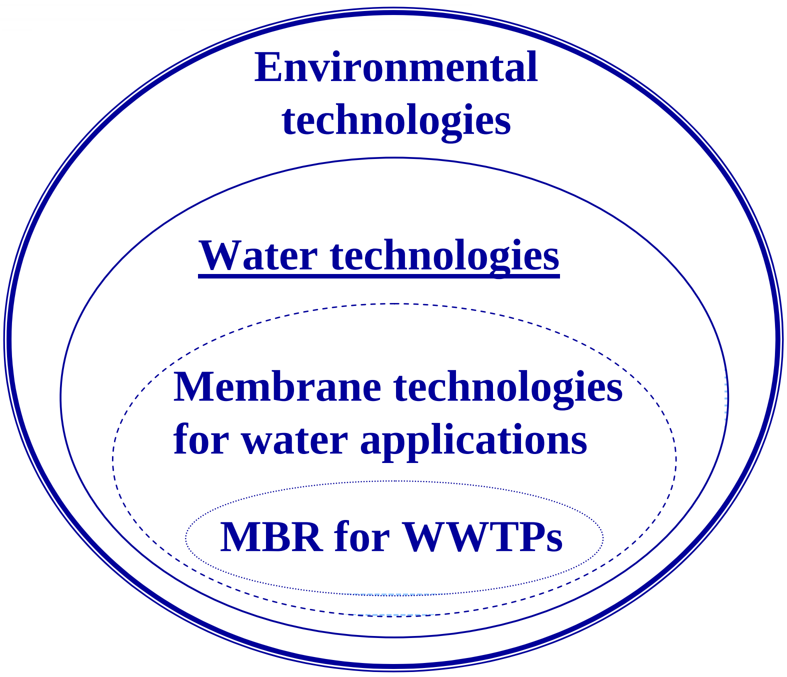
The growing MBR market in Europe



Project AMEDEUS, 2009

Slide 3

Overall research context: Environmental technologies

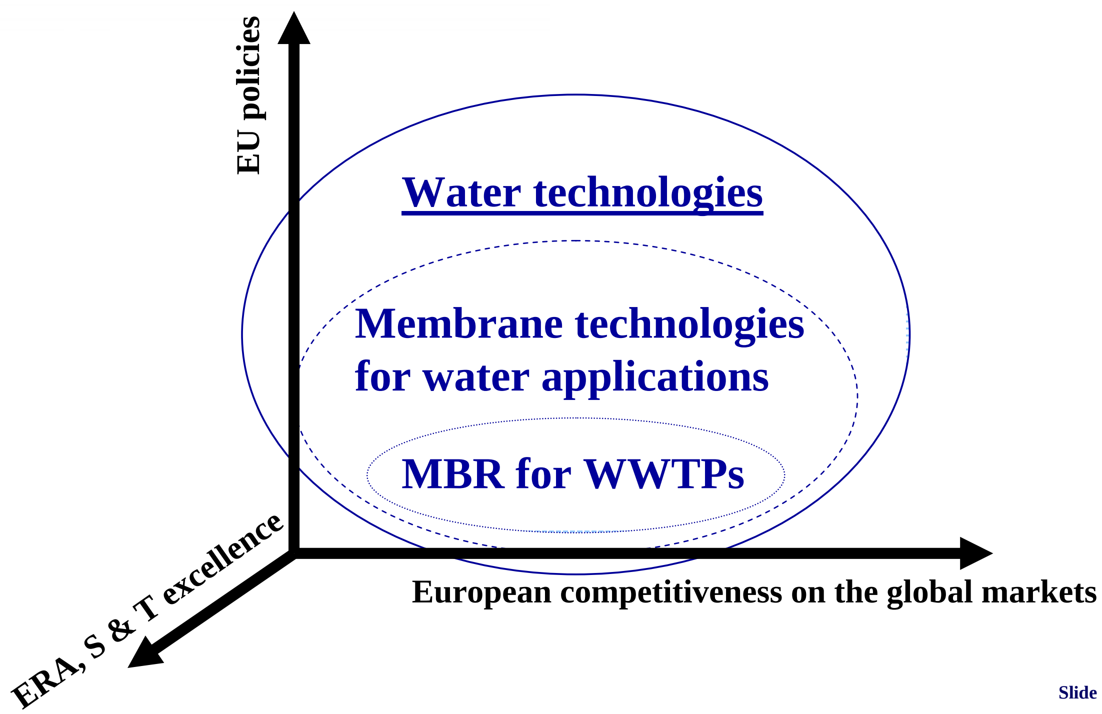


Slide 4

Water technologies: Past / ongoing EU research

- Technologies for municipal waste water treatment
- Water treatment for industries
- Artificial aquifer recharge with reclaimed water
- Nano-structured membranes for water filtration
- Technologies for safe sewage sludge treatment and disposal
- Advanced membrane-based desalination
- Technologies for drinking water production and distribution

Three axes for a research strategy



EU Policies
Competitiveness and markets

- ✓ **Recovery Plan (2008)**
- ✓ **Lisbon Strategy (2000, 2005)**
- ✓ **SDS (2001, 2006)**

EU policies

Policy instruments (e.g. Directives, Action Plans) may:

- **Formulate objectives** (to be achieved within a pre-defined time-scale)
- Call for overall **management plans** and **protection measures**
- Specify **limit values** for concentrations of priority substances
- Specify general **technical requirements** (e.g. BATs)
- Specify **rules for monitoring**
  - List of parameters to be monitored, analytical method and sampling frequency
- **Set standards** and reporting procedures for parameters to allow for later assessment.
- Usually foresee **periodic progress reviews**
  - revision of the legislation when appropriate

European competitiveness on the global markets

Slide 7

Examples of EU Policy drivers for water Community research

- ✓ **Environmental Technology Action Plan - ETAP (2004)**

EU environmental policies

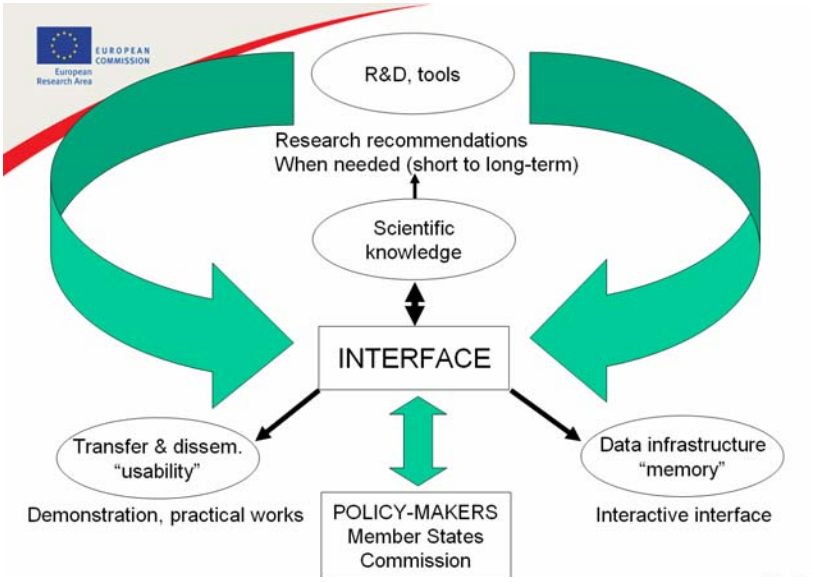
- 2007 – **Flood** Directive
- 2007 – **Water Scarcity and Drought** Communication
- 2007 – Green Paper "**Adapting to climate change** in Europe"
- 2006 – **Groundwater** Directive
- 2006 – New **Bathing Water**
- 2006 – First list of priority hazardous substances
- 2000 – **Water Framework Directive**
- 1998 – **Drinking Water** Directive
- 1996 – Directive concerning Integrated Pollution Prevention and Control
- 1992 – Habitats and Birds Directive
- 1991 – Urban **Waste water** treatment Directive
- 1991 – Nitrates Directive
- 1986 – **Sewage Sludge** Directive

European competitiveness on the global markets

Slide 8

EUROPEAN COMMISSION
European Research Area

Science - policy interface



EU environmental policies

✓ **Common Implementation Strategy (CIS) of the Water Framework Directive**

ERA, S & T excellence

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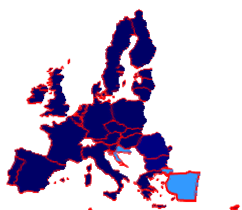
European Research Area

EU Policies
Competitiveness and markets

European competitiveness on the global markets

ERA, S & T excellence



MBR-Network
European cluster dedicated to membrane bioreactor technology

WSSTP

EMH European Membrane House

EMS European Membrane Society

European Desalination Society

Research strategy (1/2)

- **Several motivations:**
  - To strengthen the European water industry
  - To strengthen the European Research Area
  - To help implementing EU environmental policies
  - To provide cost-effective solutions to water treatment operators
- **Driven by what markets will deliver in 2020-2025**
  - 10^{+} years to go from labs to markets
- **Use of a panoply of RTD instruments**
  - Upstream/downstream research, demonstration, benchmarking, training, awareness raising, standardisation, innovation and up-take, coordination…
- **Involves multidisciplinary consortia**
  - Consolidated user community, industrial networks of SMEs and larger players, centres of S & T excellence, policy makers

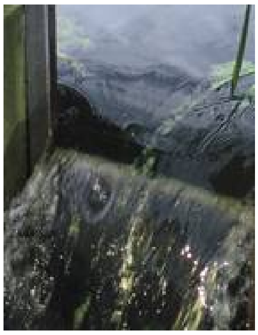
Slide 11

Research strategy (2/2)

- **Particular attention to up-scaling issues**
  - From molecules to pilot plants and markets
- **Requires a case-study approach**
  - With public and private end users' involvement
  - Cost-effective in various operational water treatment contexts
- **System approach: towards highly controllable and modular wastewater treatment plants**
  - Optimised performance according to needs/time, customers and wastewater contexts
  - Reduce local ecological footprint
- **Life cycle assessment**
  - Greenhouse gases emissions (such as NO, NO2, CH4 and CO2)
  - Energy consumption
  - Routes of involved toxicants in water and sludge
- **Other recurrent issues include notably:**
  - Wastewater characterisation, membrane fouling, hybrid membranes, sludge age, sludge disposal, effluent re-use, costs of purchase and maintenance, training of operators

Slide 12

Thank you for your attention



Emerging research topics

Research topics proposed by the membrane and water communities include notably:

- Alternative filtration techniques (e.g. microtextile)
- Alternative membrane systems (e.g. anaerobic systems, algae membrane bioreactors)
- Techniques for reduced fouling, alternative cleaning strategies
- Reduction of harmful by-products resulting from wastewater treatment, recycling of usable by-products
- Lower energy systems
  - New technologies for low energy desalination
- Easy customisation / optimisation of membrane systems integrated into hybrid treatment plants
- Operation/maintenance costs
  - Centralised versus decentralised systems
- Etc …

✓ **To be consolidated and reviewed**

3. TRENDS IN WORLDWIDE MBR RESEARCH AND COMMERCIAL APPLICATIONS IN NORTH AMERICA

Nazim Cizek

Trends in Worldwide MBR Research and Commercial Applications in North America

Nazim Cicek,
Associate Professor

Wenbo Yang,
PhD Candidate

Department of Biosystems Engineering
University of Manitoba, Canada

MBR Related Conferences

- Water Environment- Membranes Technology
  Seoul, South Korea
  June 2004
- Membranes for Water and Wastewater Treatment
  Harrogate, UK
  May 2007
- International Membrane Science and Technology Conference
  Sydney, Australia
  November 2007
- Membrane Technologies in Water & Wastewater Treatment
  Moscow, Russia
  June 2008
- North American Membrane Research Conference
  Amherst, MA, USA
  August 2008
- Aquatech 2008: Design and operation of membrane plants
  Amsterdam, The Netherlands
  October 2008
- 5th IWA Specialized Membrane Technology Conference
  Beijing, China
  September 2009
- Membrane Technology and Water Reuse
  Istanbul, Turkey
  October 2010

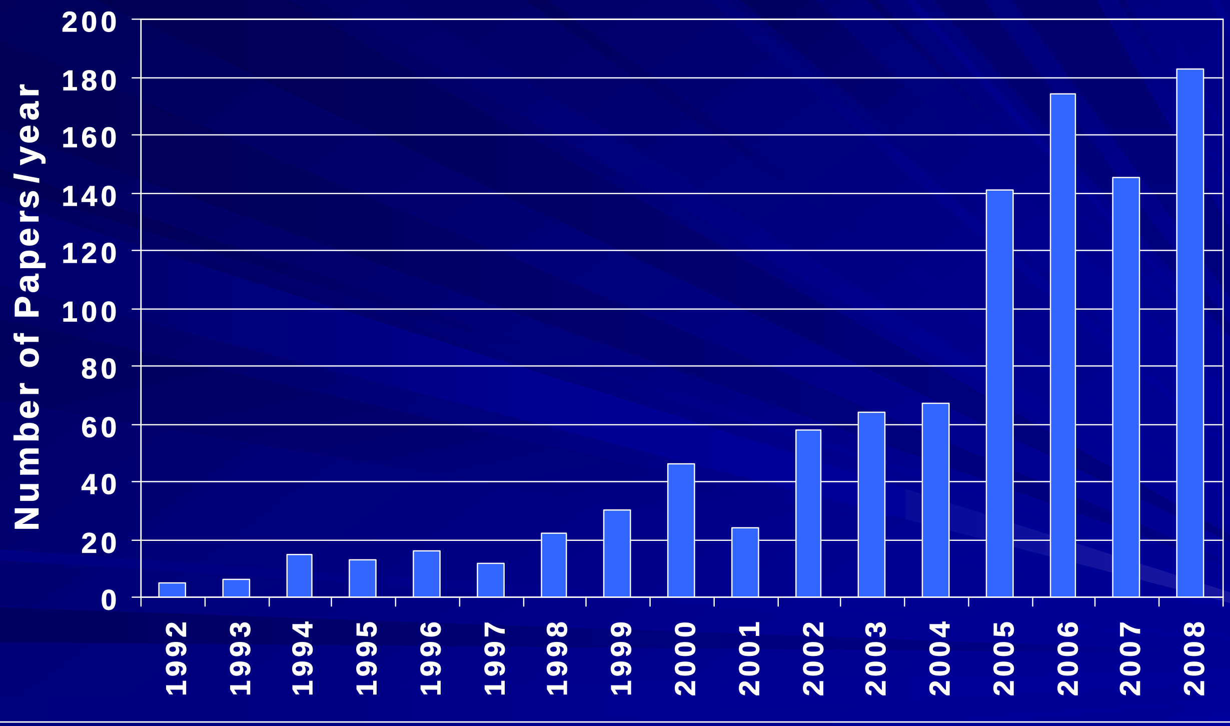
Scope

- Summarize the research status on MBRs based on a worldwide literature search
- Present recent global and North American trends and compare with 2004 study
- Touch on MBR commercial developments in North America

Study Methodology

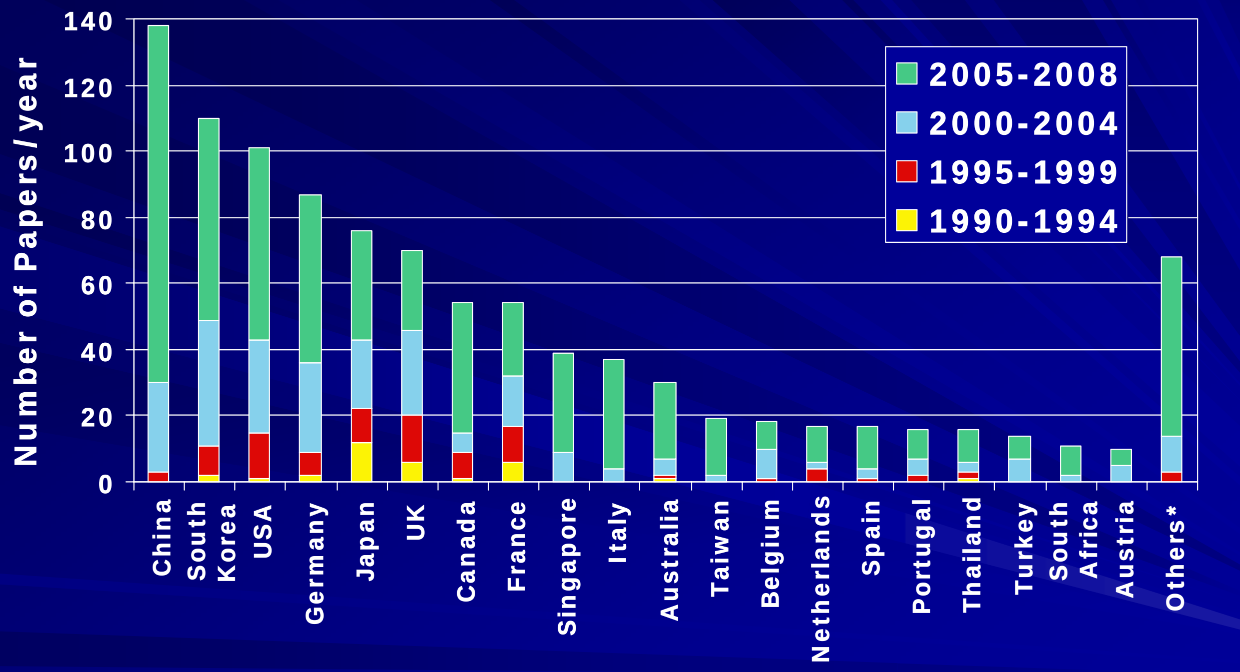
- A total of 1027 research papers published in peer-reviewed international journals from 1991 to 2008 were compiled in a searchable database
- Information on full-scale MBR installations in North America were obtained from GE-Zenon
- All municipal installations larger than 1 MGD (4MLD) and industrial installations larger than 0.1 MGD (0.4MLD) were assessed in detail

Worldwide MBR Journal Publications



IWA, MBR-Network Workshop,
Berlin, March 31st - April 1st, 2009

Geographical Distribution



*Total of 19 countries including Israel, Brazil, Norway, Poland, Croatia, Switzerland, with less than 10 publications overall

IWA, MBR-Network Workshop,
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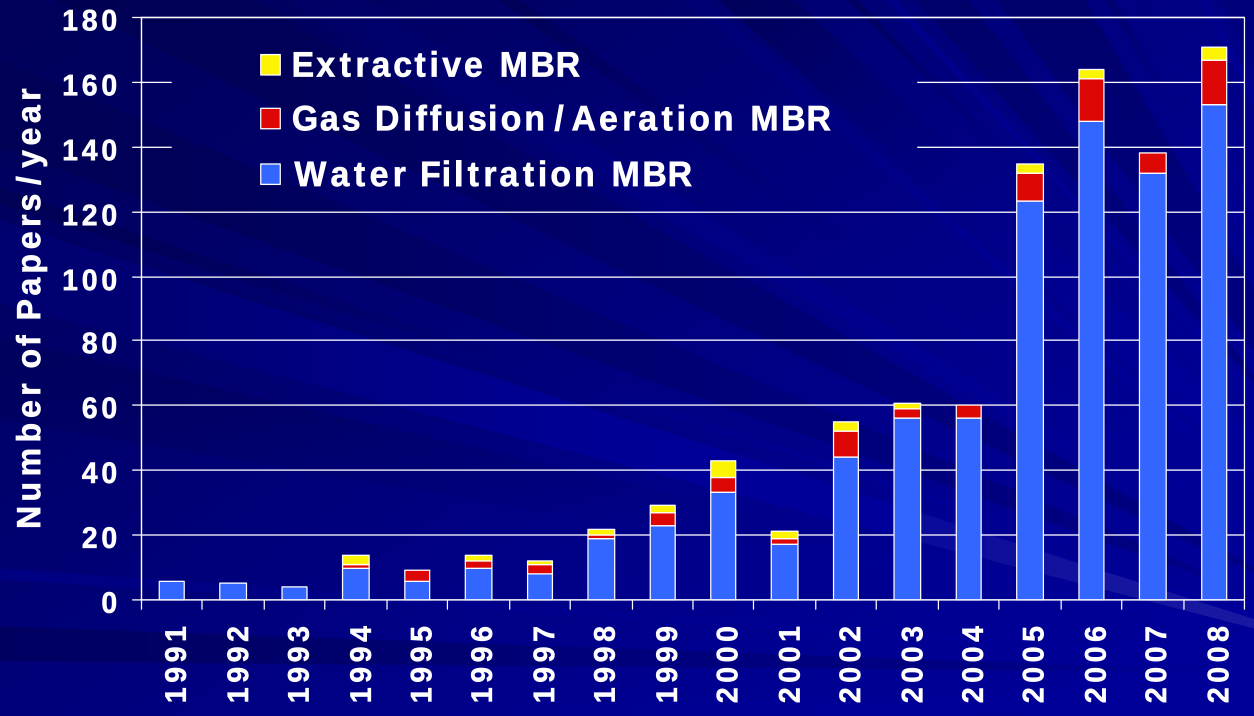
Main Types by Filtration



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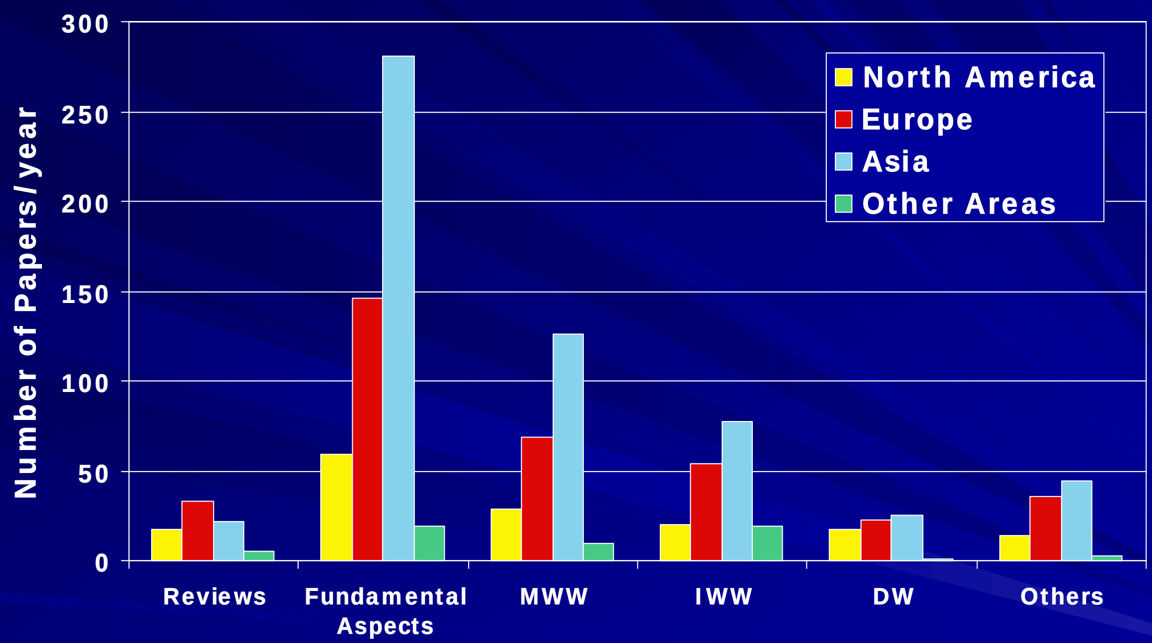
MBR Research Areas



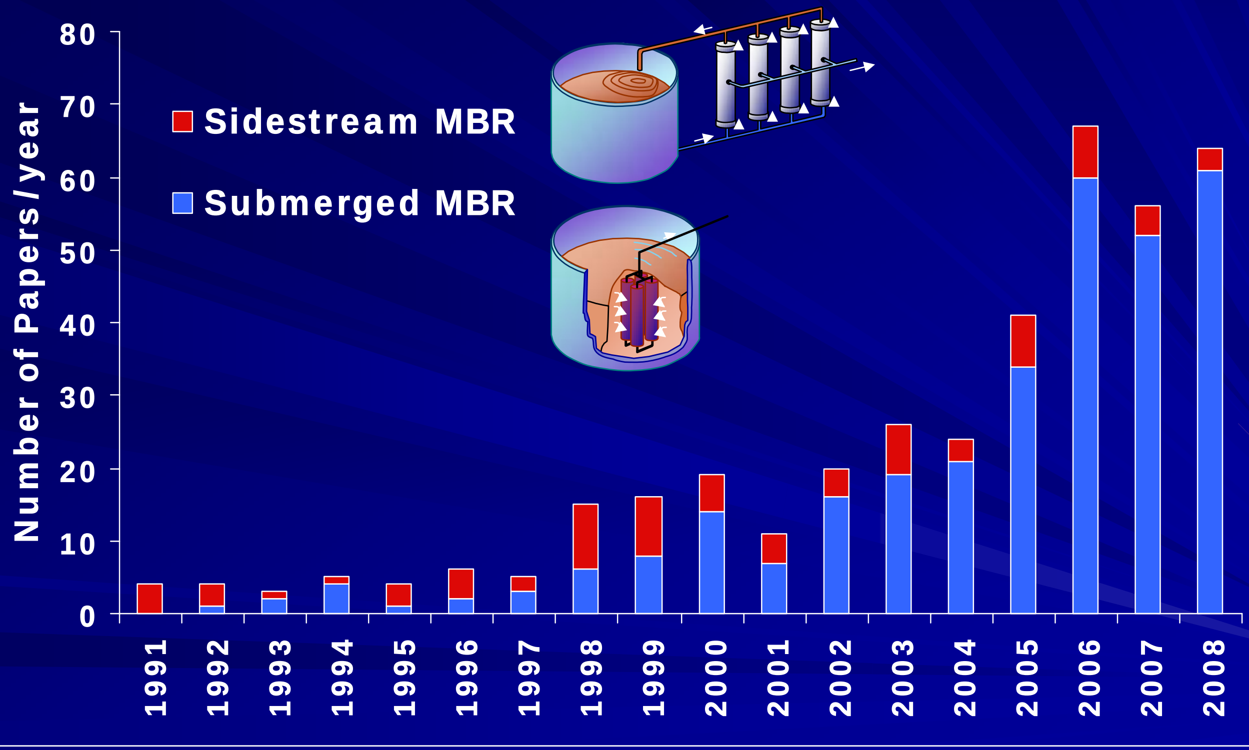
Fundamental Aspects: fouling, operation and design parameters, sludge properties, bacteria characteristics, cost, modeling)
Others: gas treatment, sludge treatment, priority pollutants. etc

IWA, MBR-Network Workshop,
Berlin, March 31st - April 1st, 2009

Some Observations…

- Since 2005, focus has switched from feasibility studies to fundamental aspects (FA)
  - Pre-2005: ~20% of all studies on FA
  - By 2009: ~50% of all studies on FA
- More than 80% of all FA papers involved membrane fouling (this was less than 40% prior to 2005)
- Asia based research has moved from primarily application/feasibility studies to FA since 2005
- North American research was predominantly in the industrial wastewater area prior to 2005 and is now exhibiting a similar pattern to the rest of the world

MBR Research Configurations



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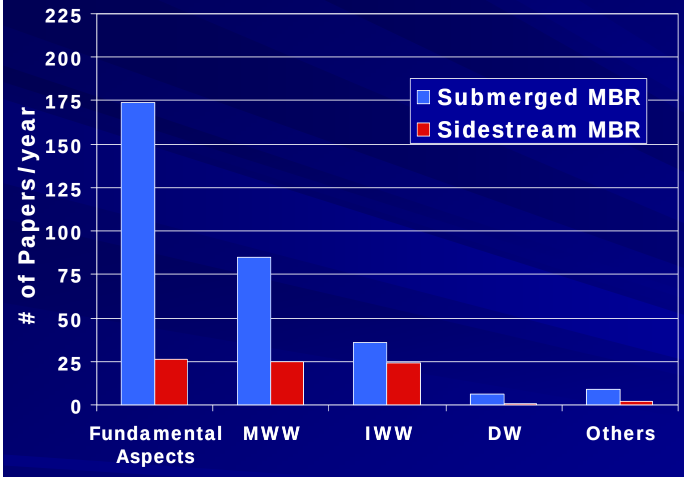
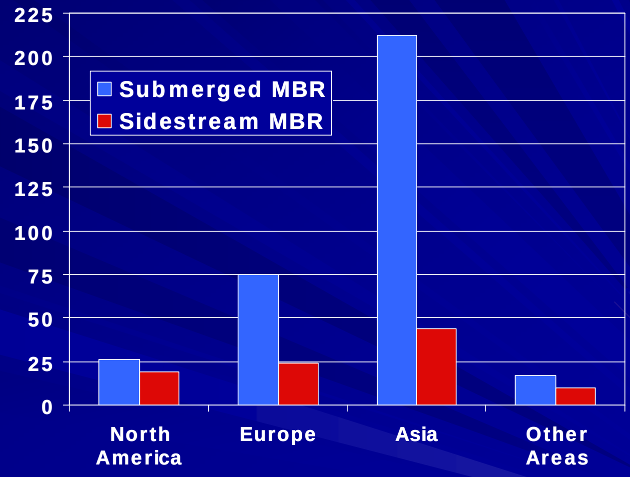
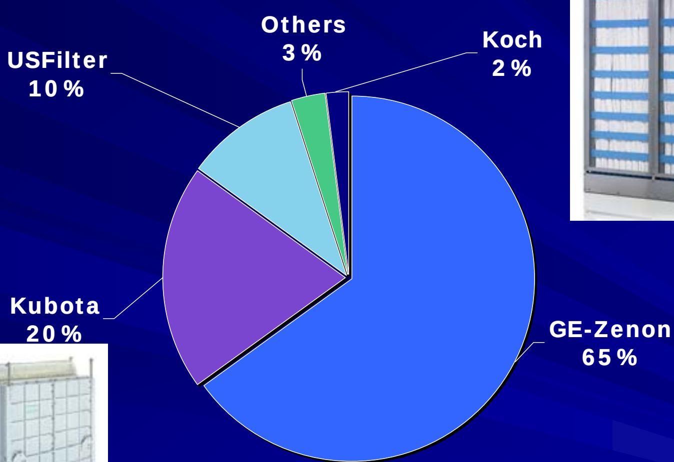
MBR Research Configurations (Cont'd)





MBR Providers in North America



NA Market Share, Revenue
Graeme Pearce, 2008

Largest Operating MBRs in NA

Location	Technology	Date	ADF/MDF (MLD)
Peoria, AZ	GE/ZENON	2008	**40 / 80**
Loudon County, VA	GE/ZENON	2008	**40 / 50**
Tempe Kyrene, AZ	GE/ZENON	2006	**36 / 47**
Traverse City, MI	GE/ZENON	2004	**32 / 41**
North Kent Sewer Authority, MI	GE/ZENON	2008	**24 / 37**
Redlands, CA	GE/ZENON	2004	**24 / 26**
Cauley Creek, GA	GE/ZENON	2002	**20 / 25**

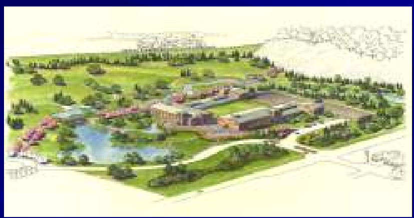
Traverse City, MI, USA

Tempe Kyrene, AZ, USA

Redlands, CA, USA

Largest MBRs awarded in NA

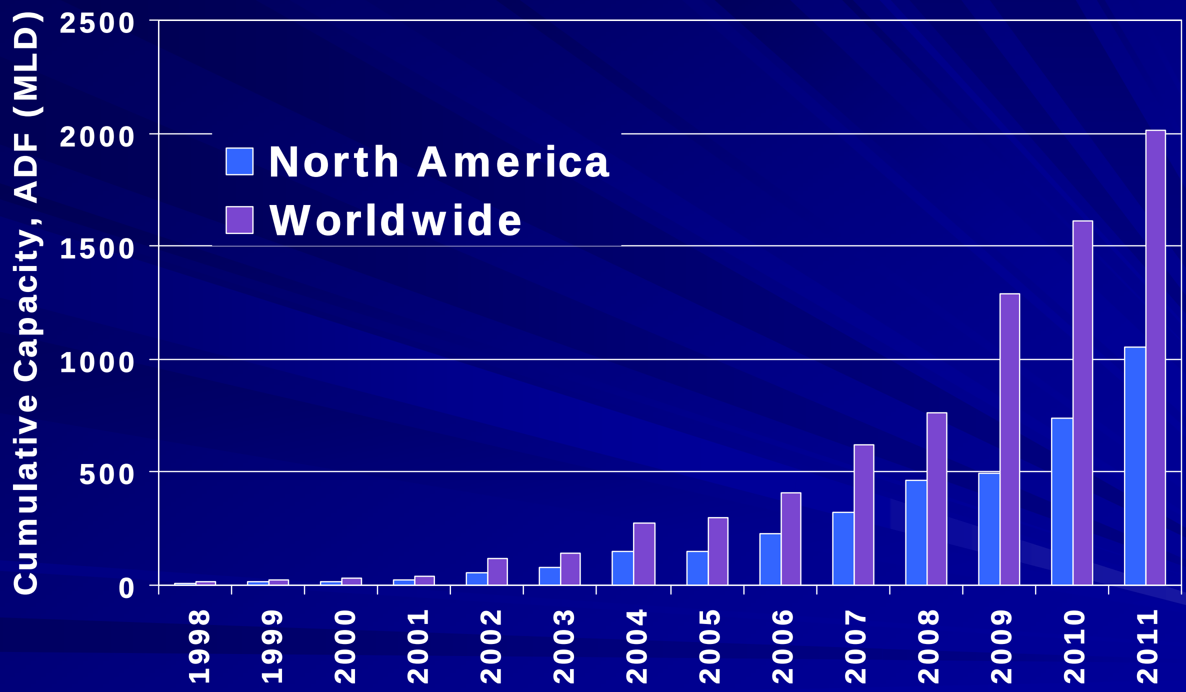
Location	Technology	Date	ADF/MDF (MLD)
Municipal MBR, NV	GE/ZENON	2012	**100 / 200**
Brightwater, WA	GE/ZENON	2011	**124 / 152**
Frederick County, MD	GE/ZENON	2011	**60 / 140**
Yellow River, GA	GE/ZENON	2011	**73 / 119**
Johns Creek, GA	GE/ZENON	2010	**44 / 97**
Jordan Basin WRF, UT	GE/ZENON	2010	**56 / 84**



Johns Creek, GA

Brightwater, WA

Municipal GE-Zenon MBRs larger than 1MGD (4MLD)



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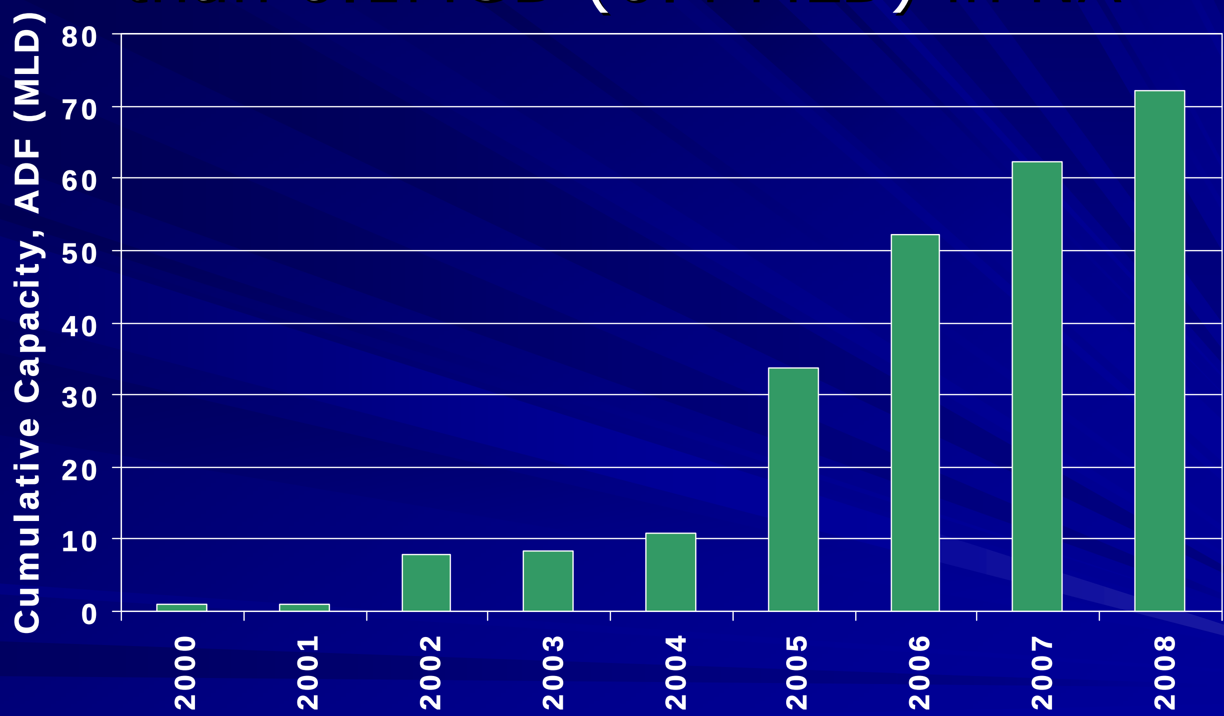
Industrial GE-Zenon MBRs larger than 0.1MGD (0.4 MLD) in NA



IWA, MBR-Network Workshop,
Berlin, March 31st - April 1st, 2009

Industrial GE-Zenon MBRs larger than 0.1MGD (0.4 MLD) in NA

Wastewater source	Number of plants	Total Capacity (MLD)
Food and beverage processing	14	52.0
Chemical plant	5	11.6
Manufacturing	3	2.8
Pharmaceutical plant	2	0.8
Automotive plant	1	1.6
Dairy plant	1	0.8
Total	**26**	**69.6**

Potential Expansion Areas in North America

- Larger-scale municipal wastewater treatment and water reuse
- Future Expansion in Industrial Wastewater
  - Food Processing
  - Slaughterhouse wastewater
  - Intensive Livestock production facilities
  - Landfill Leachate
- EDCs, Pesticides, Pharmaceuticals, SOCs removal from water or tertiary wastewater
- Full BNR plants, with more stringent phosphorus and nitrogen standards (requiring solids free effluent)
- Novel processes (Annamox, membrane biofilm reactors, anaerobic systems, fermentation etc.)

Closing Thoughts…

- Research
  - There is a shift in MBR research to Asia, particularly China and South Korea
  - Research is more widespread globally
  - North American research is unique with relatively more emphasis on sidestream MBRs
- Applications in North America
  - Submerged MBRs have now emerged as a mainstream technology
  - Installation capacity continues to increase exponentially
  - Many potential areas of expansion and significant future growth can be expected
  - Water re-use, tightening discharge standards, continued urbanization are main drivers behind MBR expansion in municipal wastewater in North America

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4. MBRS AND THE TMP JUMP - SELF ACCELERATING FOULING PHENOMENA

Tony Fane

MBR-Network Workshop, Berlin, March 2009.

MBRs and the TMP Jump
- Self Accelerating Fouling Phenomena

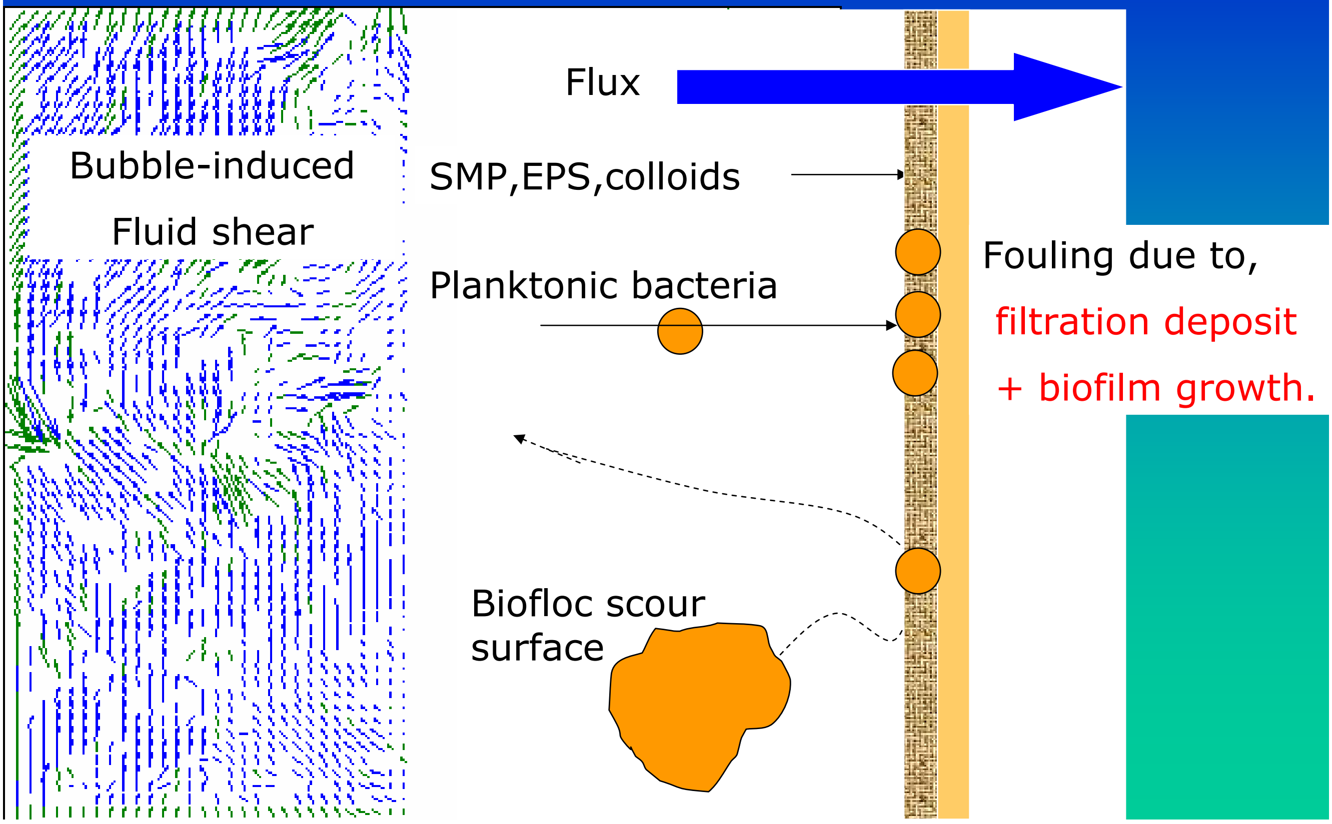
Tony Fane,

Singapore Membrane Technology Centre, NTU, Singapore
UNESCO Centre for Membrane Science and Technology, UNSW, Australia

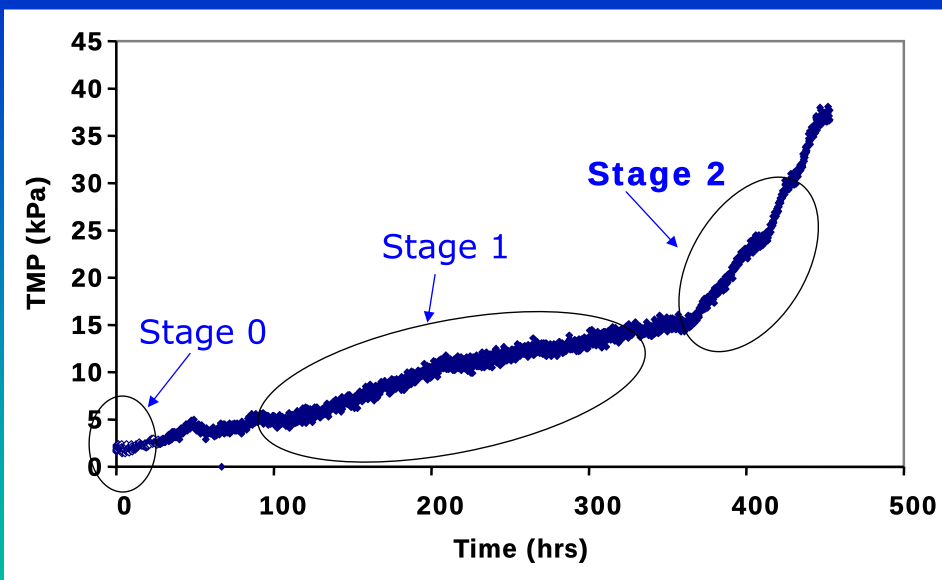
Contents

- Introduction.
- Fouling Stages and the TMP Jump.
- Possible Mechanisms.
- Conclusions

Membrane Fouling Mechanisms



MBR Fouling 'history'

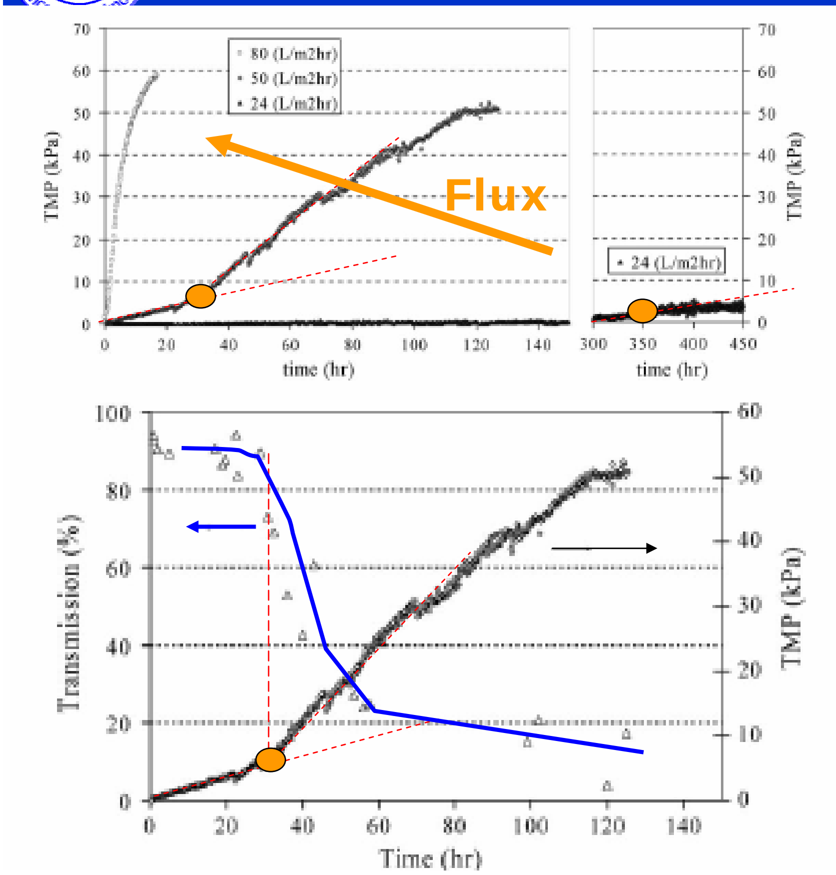


- Stage 0 Initial conditioning (mins-hrs)
- Stage 1 Slow 'sustainable' fouling (weeks)
- Stage 2 TMP jump (hrs-days)

Fouling is a function of flux; = *f* (Flux)

Constant flux leads to accelerating fouling

TMP Jump is not exclusive to MBRs



TMP jump observed with alginate feed.

TMP jump and a decrease in transmission coincide.

Y.Ye et al., Evolution of fouling during crossflow filtration of model EPS, J.Memb.Sci., 264 (2005)

Stage 2 ~ TMP Jump

~ Possible Mechanisms

- Local Area loss model
- Local Pore loss model

Local flux suddenly > critical flux value

- Critical suction pressure ~ deposit collapse
- Percolation theory ~ deposit layer fills up

Cake porosity < critical value

- Osmotic effects

Retention of organics & Cake Enhanced OP

- Inhomogeneous fibre bundle

- Lumen ‘obstruction’

Hollow issues:

- Local flow variation in bundle causes blocking.

- Stagnant bubbles in lumen

Stage 3 ~ TMP Jump

~ Possible Mechanisms

- Local Area loss model
- Local Pore loss model

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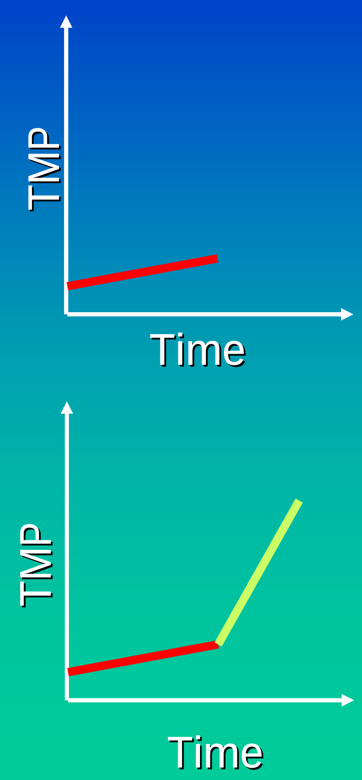
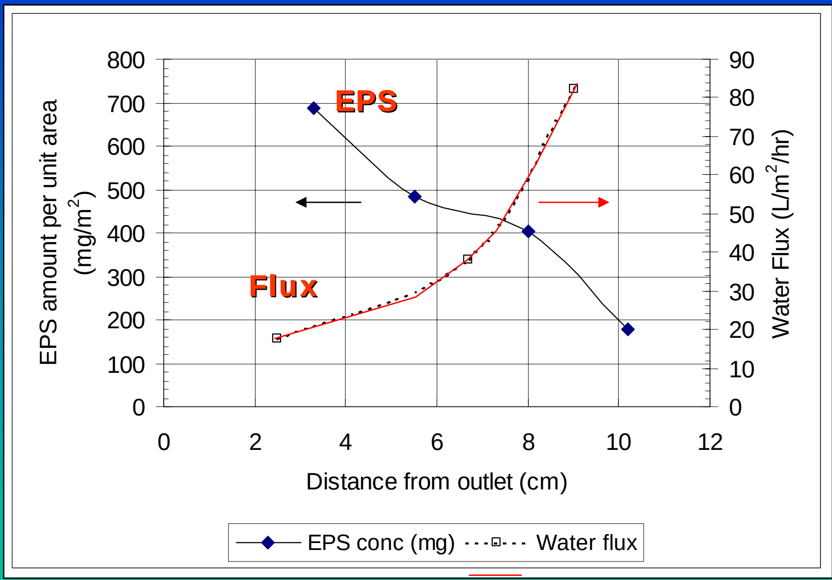
Local Area loss model

- Fouling involves two-step process
  - Step 1 : Slow rise in TMP due to slow fouling by EPS etc.
  - Step 2 : Sudden rise in TMP when local flux > critical flux of dominant foulant



Local Area Loss

Distribution of foulant and flux



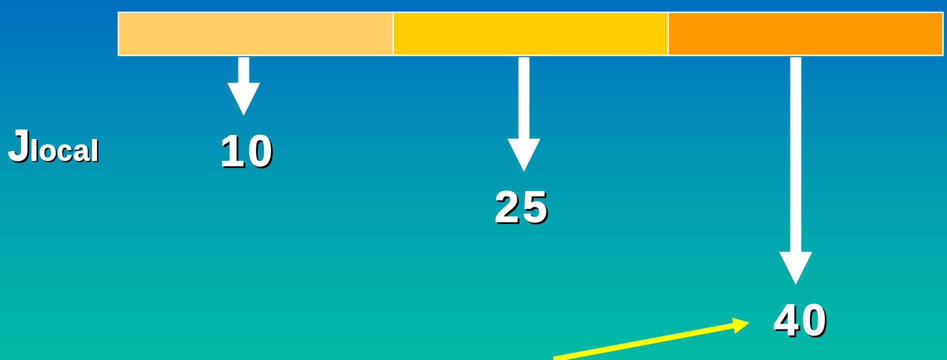
- Autopsy just before TMP jump
- EPS load varies by factor of 4x along membrane
- Water flux distribution gives, **Jmax / Jmin ~ 4**

Cho and Fane, Fouling transients in nominally subcritical flux of a MBR JMS 209 (2002)

Local Area Loss

Implications of flux distribution

- **For imposed surface-average flux of 25 l / m² / hr**



- **J_{local} can be > J_{crit} (dominant foulant)**

Similar argument applies to local pore loss model

Stage 3 ~ TMP Jump

~ Possible Mechanisms

- Local Area loss model
- Local Pore loss model

Local flux suddenly > critical flux value

- Critical suction pressure ~ deposit collapse
- Percolation theory ~ deposit layer fills up

Cake porosity < critical value

- Osmotic effects

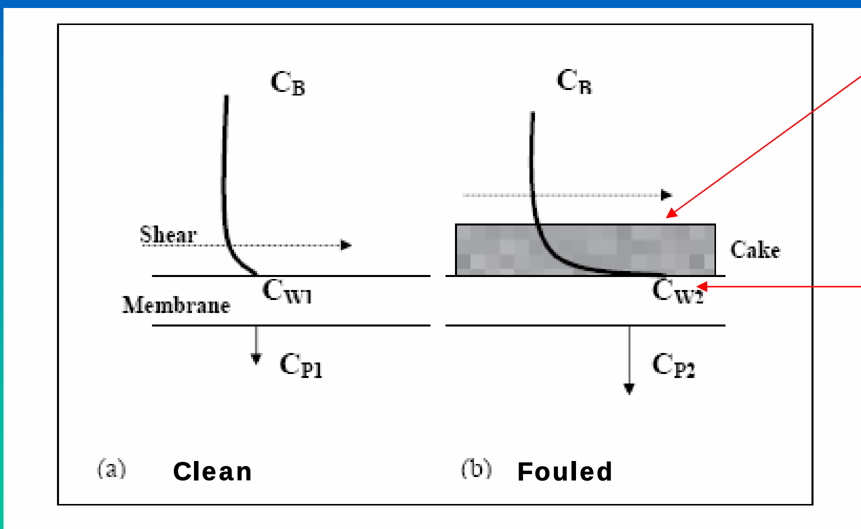
Retention of organics & Cake Enhanced OP

- Inhomogeneous fibre bundle
- Lumen 'obstruction'

Hollow issues:
- Local flow variation in bundle causes blocking.
- Stagnant bubbles in lumen

Osmotic Pressure of retained solutes and Cake Enhanced Polarization

'Cake' deposits and accumulates



Cake resistance R_F

Cake enhanced concentration Polarization*

* Hoek & Elimelech, ES&T (2003)

Chong et al.,JMS 287 (2007)

Cake Enhanced Osmotic Pressure

$$\Delta P = J\mu(R_M + R_F) + M\Delta\pi_{BP}$$

Pressure increases due to Rf + osmotic pressure

$$M = C_W / C_B = \exp(J/k)$$

Polarization increases with flux & decreases with mass transfer, k

$$k_{cake} = (D\varepsilon/\tau)/\delta_C$$

Mass transfer in deposit layer is << k in the boundary layer

Cake **height** is a key factor

CEOP can be significant effect in RO fouling.

Could it have an effect in MBRs ?

CEOP Considerations

$$M = C_W / C_B = \exp(J/k)$$

For clean membrane, $J \sim k$
M is <10 for macrosolutes.

$$k_{cake} = (D\varepsilon/\tau)/\delta_C$$

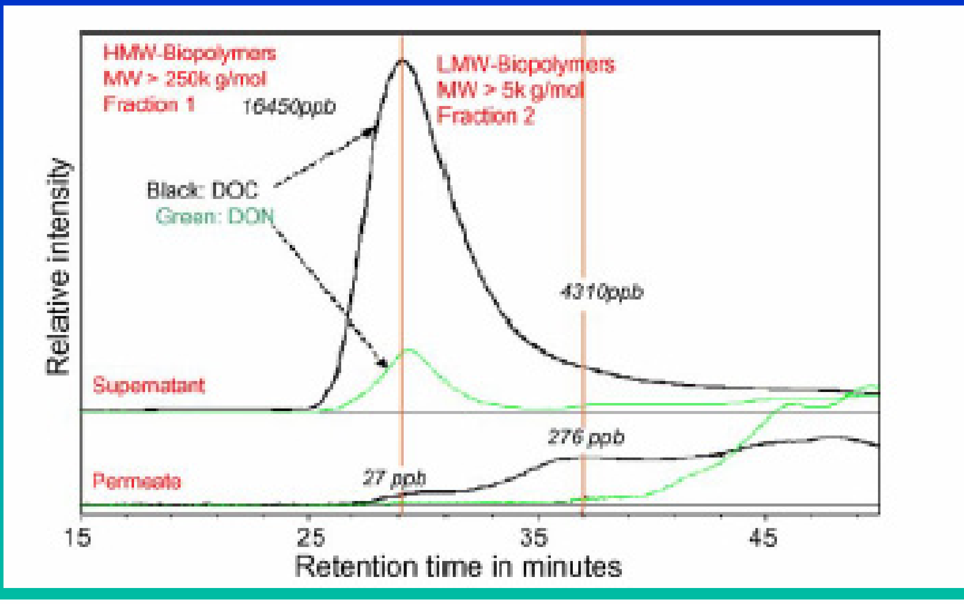
Fouled membrane, $k_{cake} << k$
$(\varepsilon/\tau) \sim 0.1$ and δ_C increasing.
$J > k_{cake}$ so M increases exponentially.

$$D = 1.56x10^{-9}\, x\, M_W^{-0.356}$$

$$\Pi = C_m RT = \frac{C}{M_W} RT$$

Solute diffusivity and osmotic pressure are related to MWt.

Supernatant & Permeate EPS

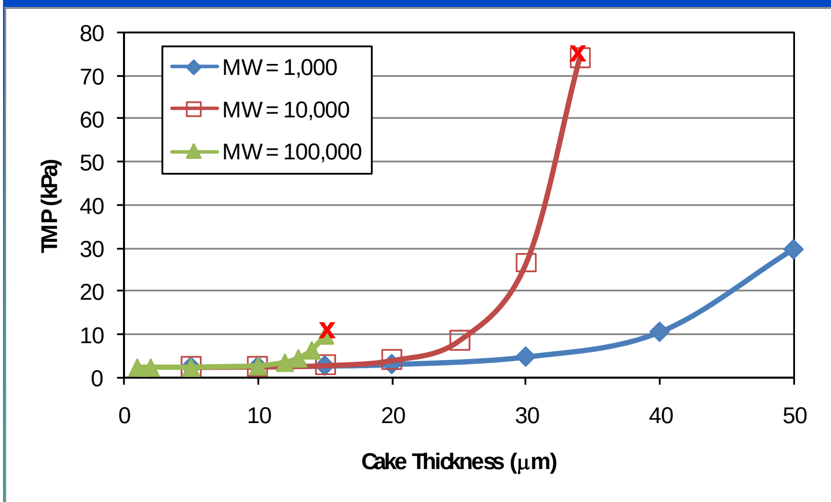


Permeate and MBR sludge supernatant content comparison

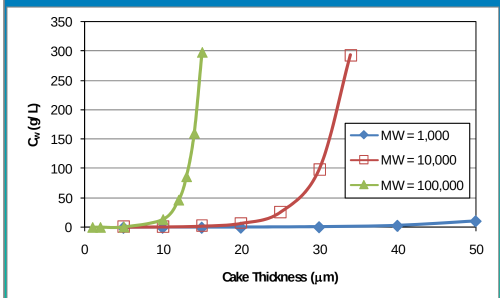
Sample	Total CDOC Hydrophilic TOC (ppb)	Approx molecular weight g/mol: fr.1 ≫ 250k, 250k>fr.2 > 5k (biopolymers in fr.1&2) TOC (ppb)	TOC %	<5000 (LMW compounds) TOC (ppb)	TOC %
Supernatant	22359	20762	[illegible]	[illegible]	7.1
Permeate	1508	303	[illegible]	[illegible]	79.9

Biopol retention 98.6% (6.5% protein 93.5% polysacch)

Significant CEOP effects appear to be possible



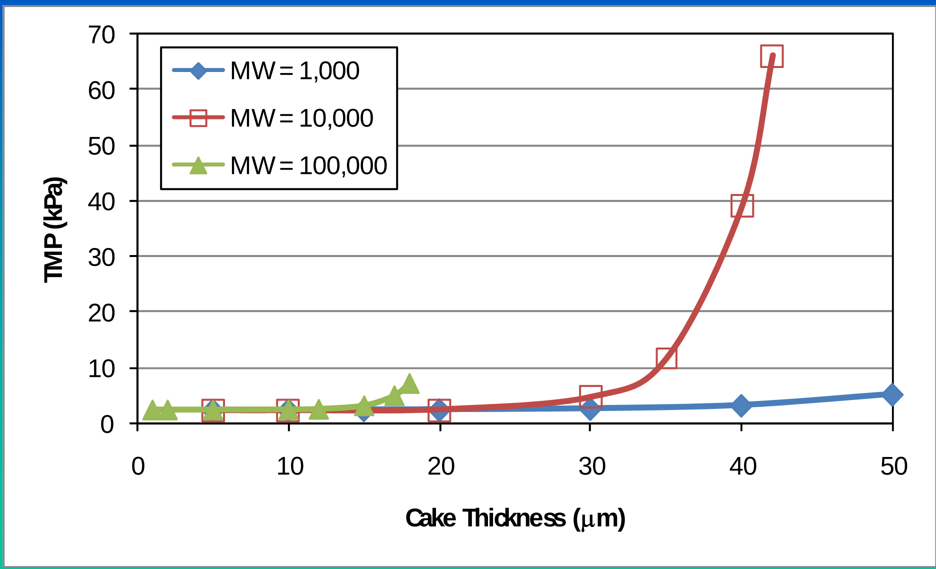
Possible gelling limit



TMP vs. cake thickness profile at various M_w with J_v = 10 LMH, C = 0.025, e = 0.45

Lower Supernatant Concentration

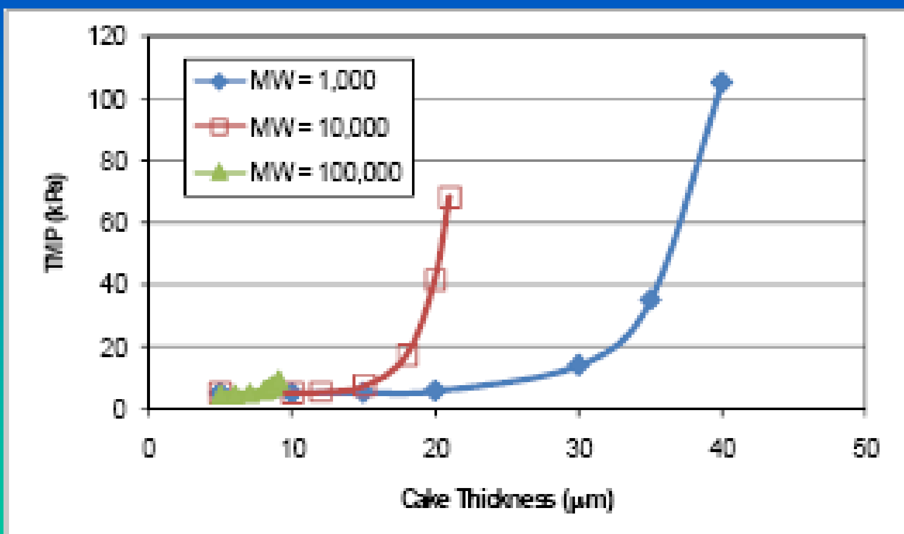
Delays CEOP until δ_c increases



TMP vs. cake thickness profile at various M_w with J_v = 10 LMH, C = 0.0025, e = 0.45

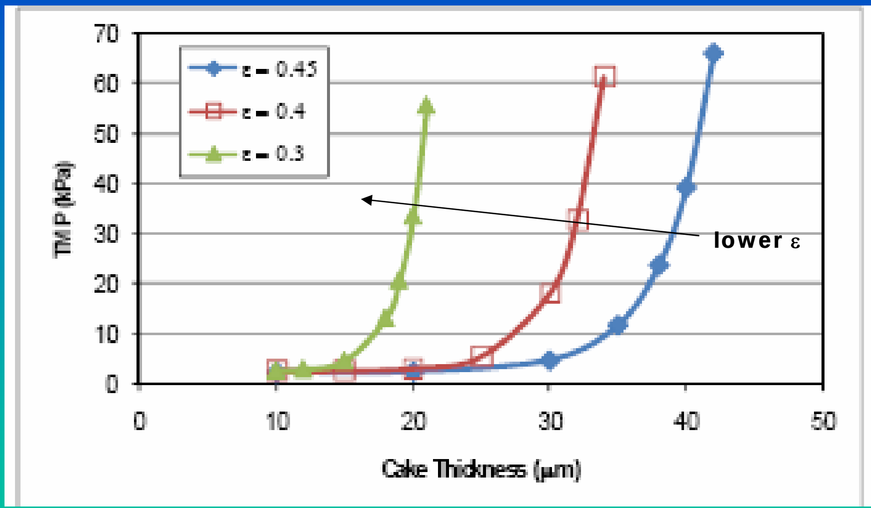
Higher Flux (20)

Earlier CEOP effect due to (exp *J/k*)



TMP vs. cake thickness profile at various M_w with J_v = 20 LMH, C = 0.0025, e = 0.45

CEOP effect increases as cake porosity decreases



TMP vs. cake thickness at various cake porosity with M_w = 10,000 g/mol, J_v = 10 LMH, C = 0.0025

CEOP effect in MBRs ?

- Cake layer (δ_C) slowly builds up
- Pores gradually close
- Retention of organics increases
- CEOP develops exponentially with δ_C
- Required TMP starts to rise rapidly.
- Implication is to minimise δ_C and avoid high fluxes . $M = \exp f(J\,\delta_C)$

- Uncertainties:
  - Osmotic pressure relationship in cake;
  - Other solute – cake interactions.

Stage 3 ~ TMP Jump

~ Possible Mechanisms

- Local Area loss model
- Local Pore loss model

Local flux suddenly > critical flux value

- Critical suction pressure ~ deposit collapse
- Percolation theory ~ deposit layer fills up

Cake porosity < critical value

- Osmotic effects

Retention of organics & Cake Enhanced OP

- Inhomogeneous fibre bundle

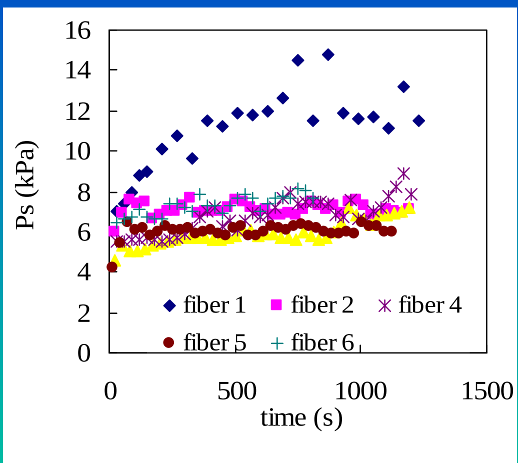
Hollow issues:
- Local flow variation in bundle causes blocking.

- Lumen 'obstruction'

- Stagnant bubbles in lumen

Lumen 'obstruction'

Low pressure in the lumen (suction) causes bubble formation.



Unstable filtration behavior observed for some individual hollow fibres operated under suction ~ MQ water

Why?

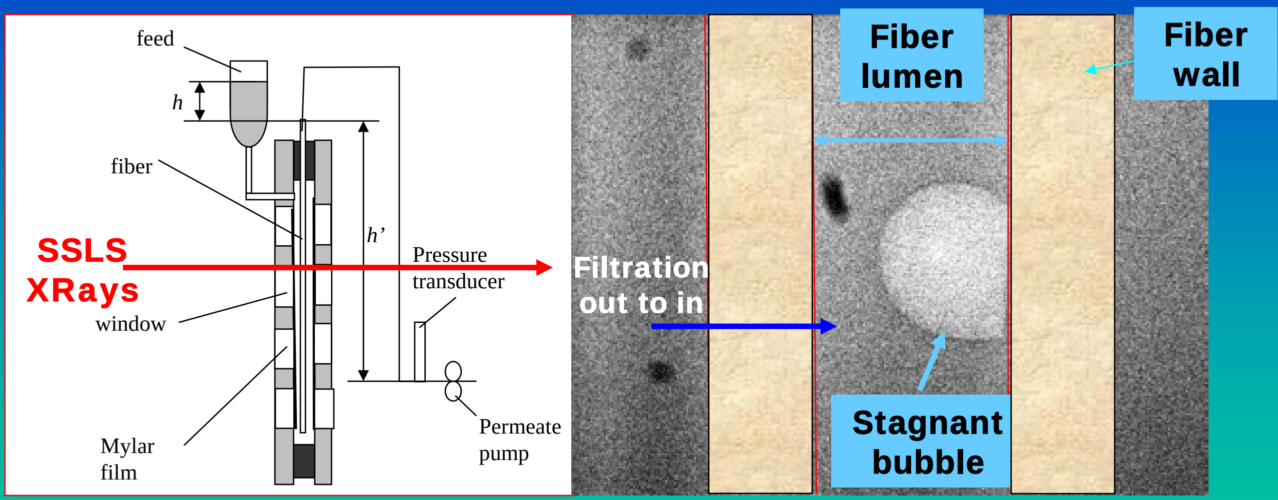
Postulated that air bubbles present in lumen cause 'obstruction' to flow

? Can we observe bubbles inside the lumen

S.Chang et al., Observation of flow characteristics in a hollow fibre lumen using non-invasive X-ray microimaging. J.Memb.Sci. 304 (2007)

Lumen 'obstruction'

- Noninvasive observation (XRMI) of bubbles in fibre lumen



Stagnant and moving bubbles observed

~ Exacerbates the TMP rise at high suction

~ Avoid high TMP, and fibres with high L/d_i

Conclusions

- In MBRs after long term 'subcritical' flux operation with a slow TMP rise, a rapid TMP 'jump' may be observed.

- Several 'self accelerating' phenomena could contribute to the jump.

- It is likely that more than one mechanism applies.

- The TMP jump can be avoided, or delayed, by modest fluxes and limiting cake formation.

ACKNOWLEDGEMENTS

Colleagues and students

at NTU and UNSW.

ASTAR & EWI Singapore

ARC Australia

5. QUORUM QUENCHING: A NEW BIOFOULING CONTROL PARADIGM IN MBRS

Chung-Hak Lee, Kyung-Min Yeon, S.Y. Kim, J.H. Kim

Final MBR-Network workshop, ***Berlin, Germany, Mar.31-Apr.1,2009***

Quorum Quenching: a new biofouling control paradigm in MBRs

Chung-Hak Lee, **Kyung-Min Yeon, S.Y. Kim, J.H. Kim**

School of Chemical and Biological Engineering,
Seoul National University, Korea

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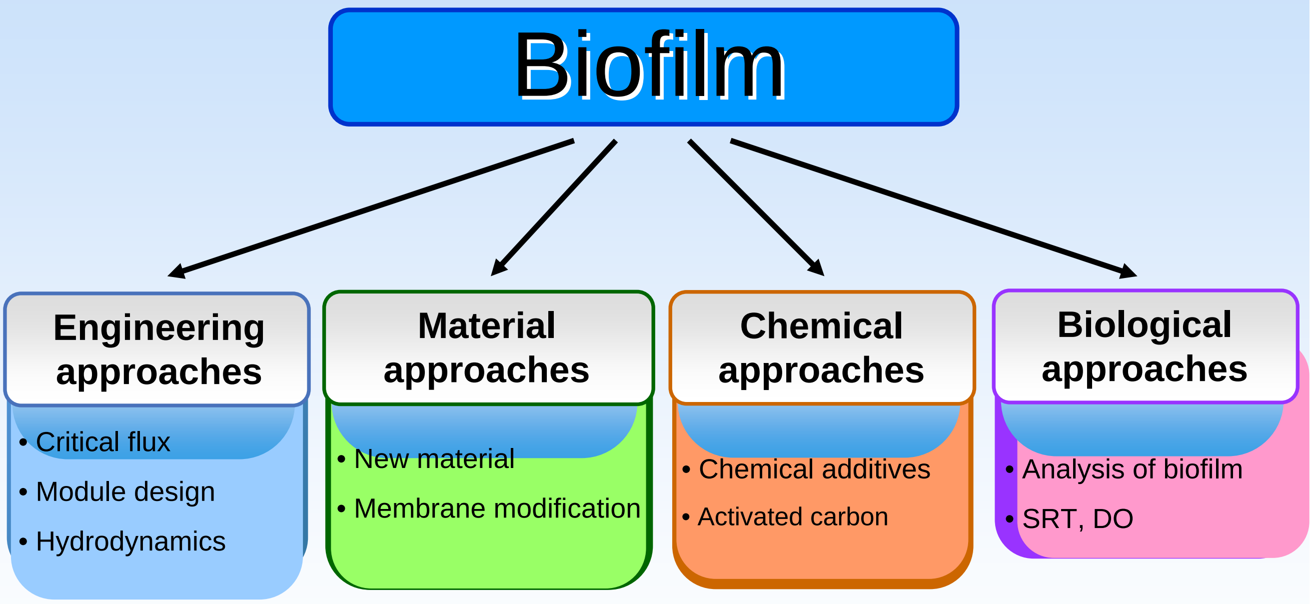
Biofilm control techniques: *Current state of the art*

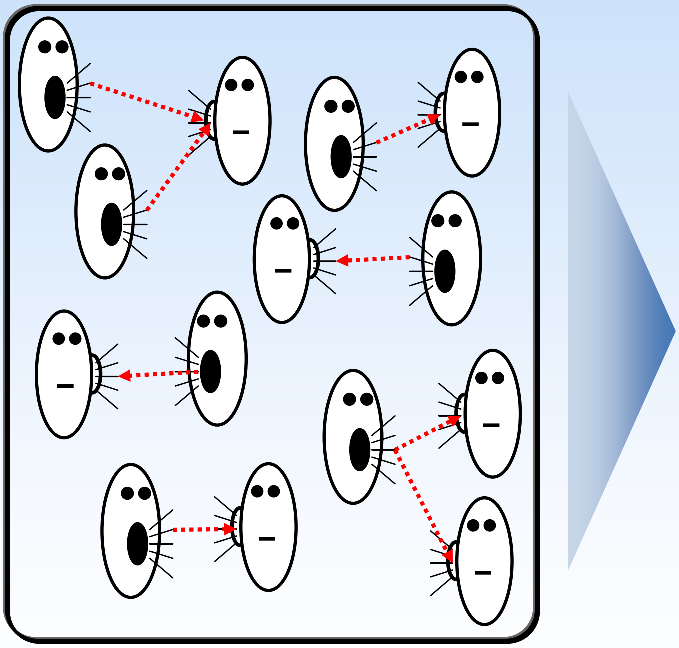


New Paradigm **: How to essentially prevent biofouling by uprooting the biofilm formation ?**

Quorum Sensing ?

Microbial community

Group behavior

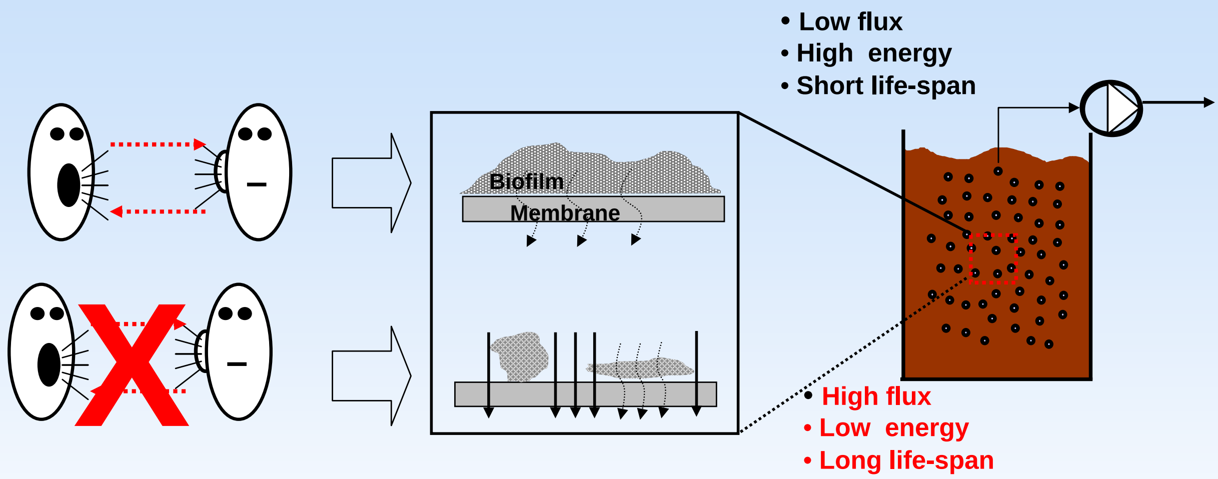


- Symbiosis
- Virulence
- Competence
- Conjugation
- Antibiotic production
- Motility
- Sporulation
- Biofilm formation

: Bacteria

: Signal molecules (autoinducer)

Quorum Quenching based biofouling control in MBR



Molecular level
(Destruction of autoinducer)

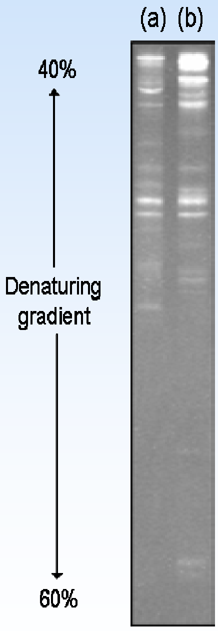
Micro-scale
(membrane-biofilm)

Engineering system
(Uproot of Biofouling)

Phase 1

Evidence of QS activity in MBR.

- **MBR sludge is undefined mixed culture system**



Column (a) :

Microbial community in membrane-biocake

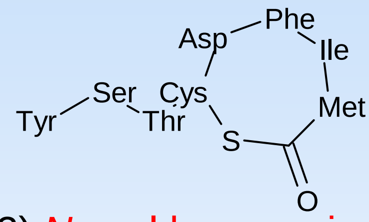
Column (b)

Microbial community in mixed liquor

PCR-DGGE :
> 10 species

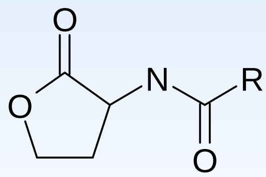
Three kinds of Autoinducers

- **1)** Modified oligopeptide of Gram-positive bacteria

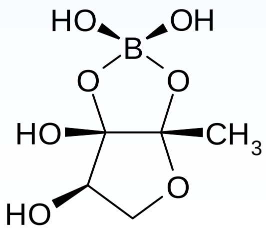


Ex. Staohylococcus aureus

- 2) *N*-acyl homoserin lactone (AHL) of Gram-negative bacteria

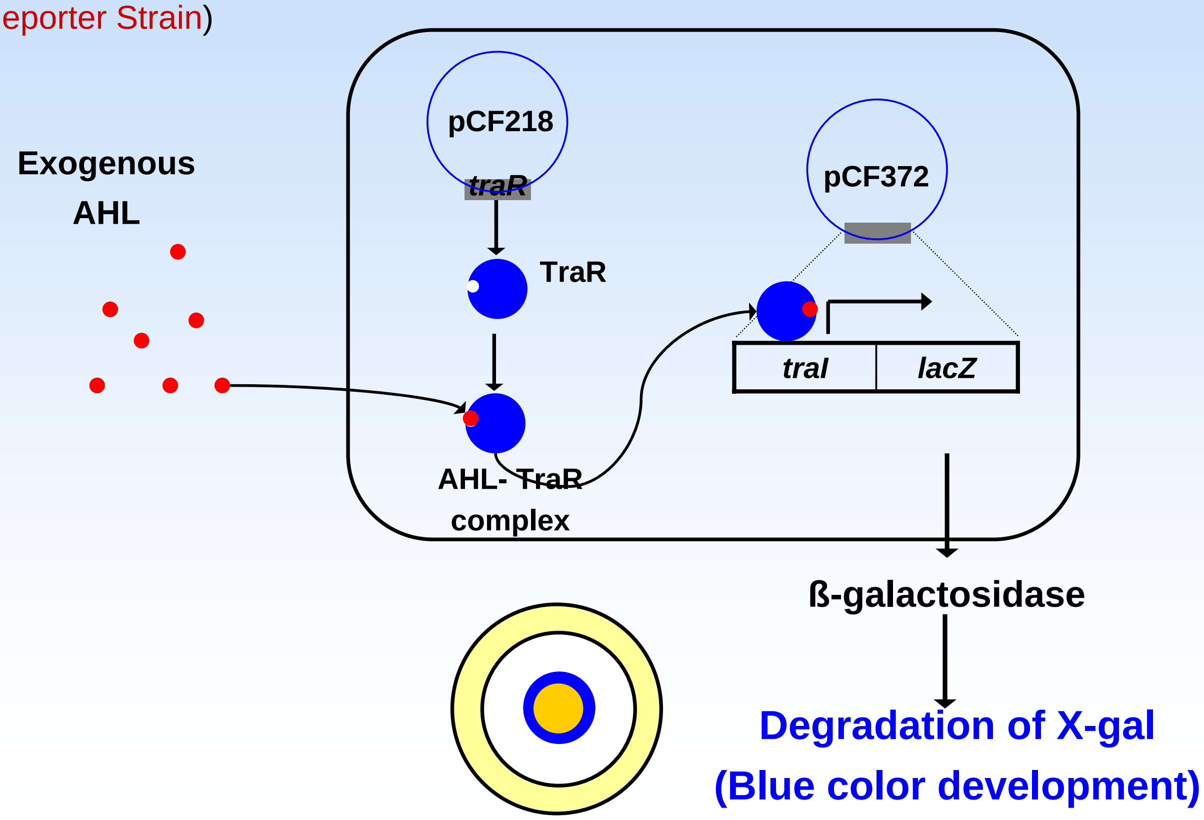


- 3) Autoinducer-2 (AI-2) for interspecies communication

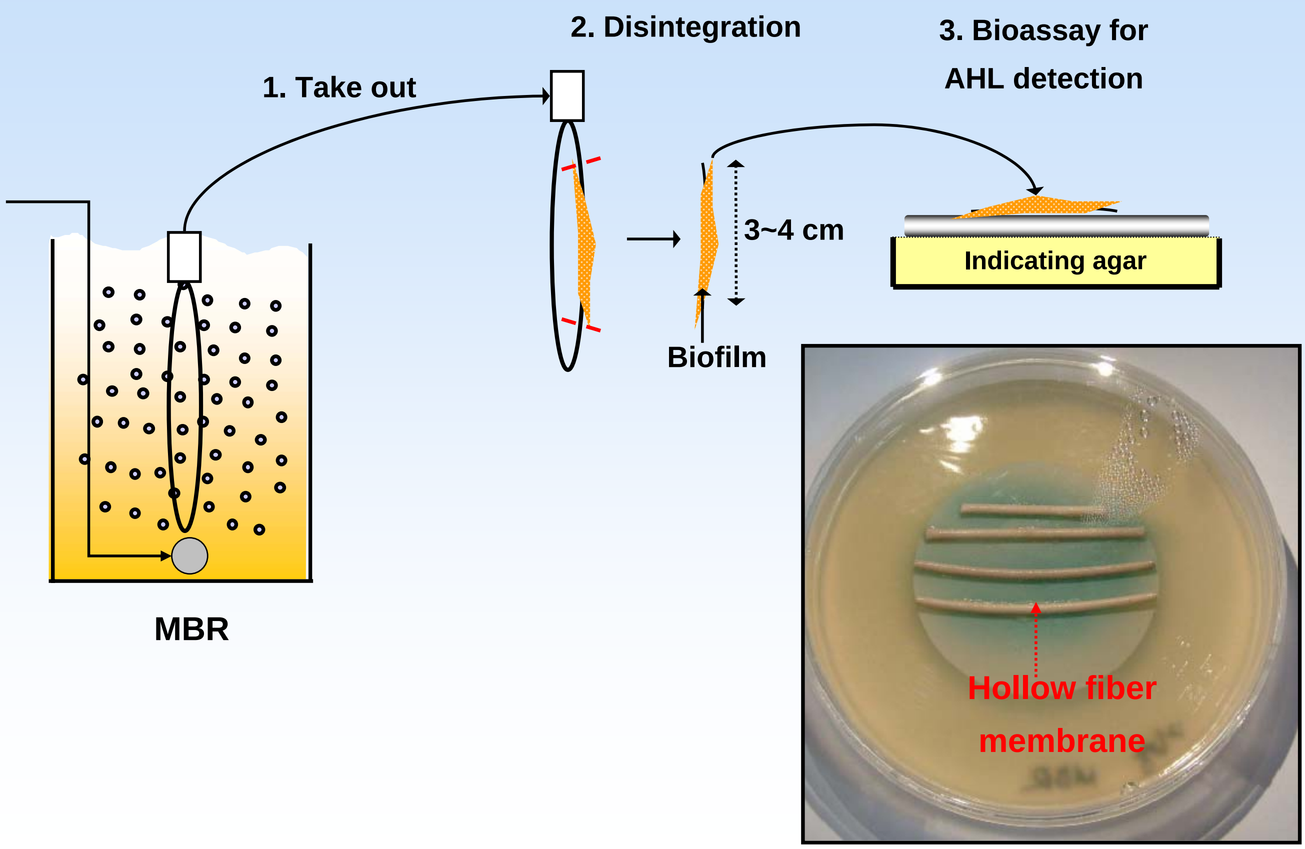


How to detect AHL : *A.tumefaciens* Biosensor

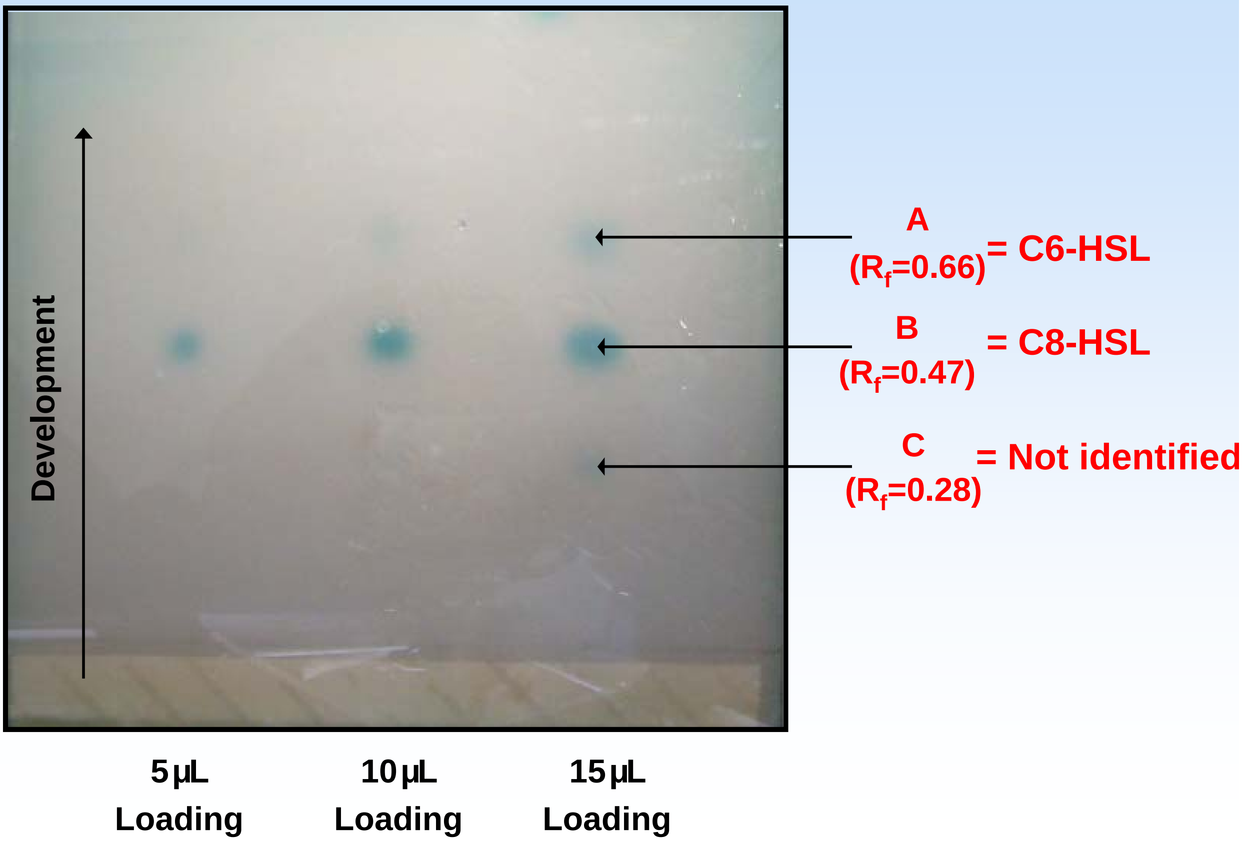
Agrobacterium tumefaciens A136 (Ti^-)(pCF218)(pCF372)
(Reporter Strain)



AHL QS activity in MBR : Experiment scheme



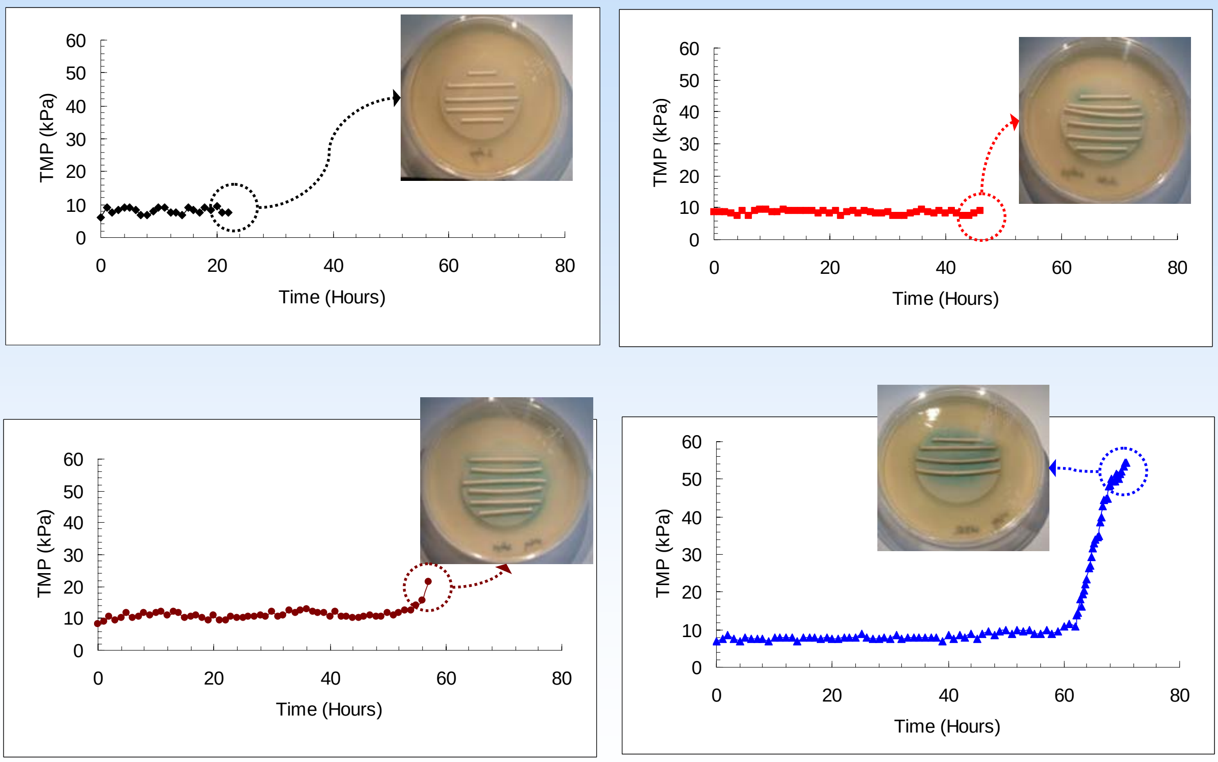
TLC chromatogram : Extracts of membrane-biofilm



Phase 2

Correlation between QS and biofouling in MBR.

Correlation between QS and biofouling in MBR

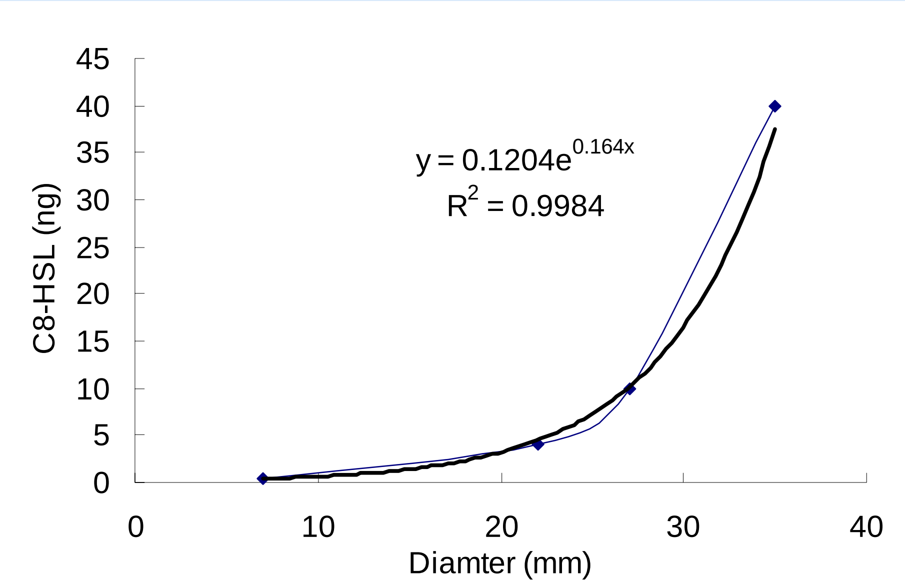


Quantitative analysis of AHL level in the sample :

- ***Calibration Curve*** (AHL standard : Synthetic C8-HSL) ;

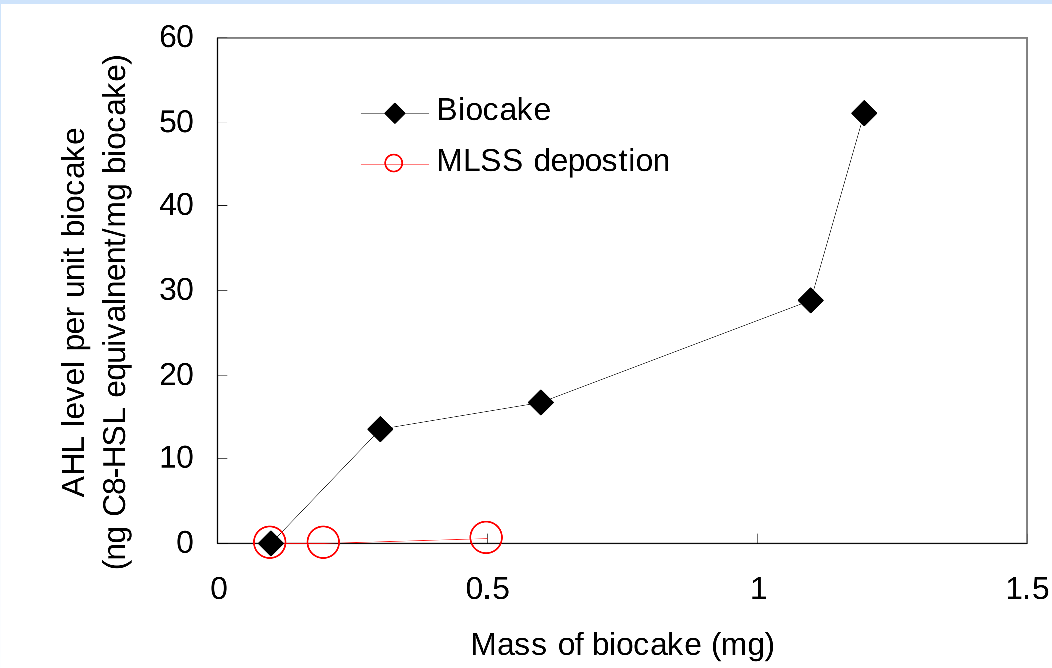
Amount of AHL (ng C8-HSL) = $0.1204\ e^{0.164X}$ (r^2=0.9984)

X: distance of blue color on bioassay agar (mm)

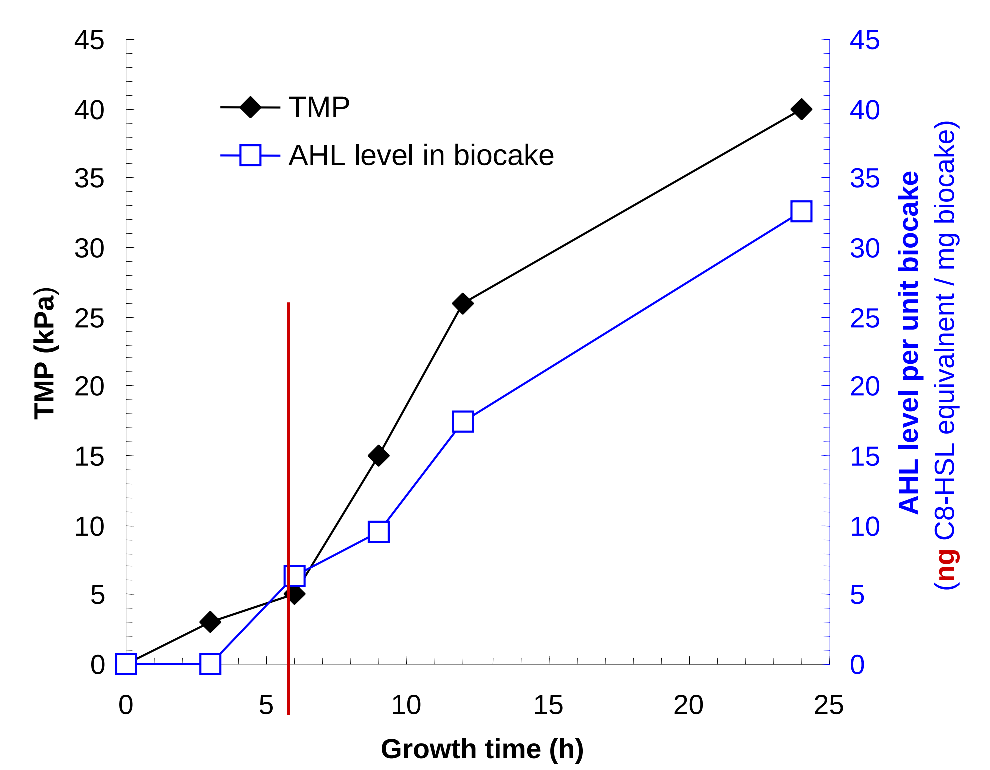


Dong et al., PNAS 2000, 97, 3526–3531.

Comparison of AHL level per unit biomass



Correlation between TMP and AHL level in membrane-biofilm



Autoinducer → self-acceleration

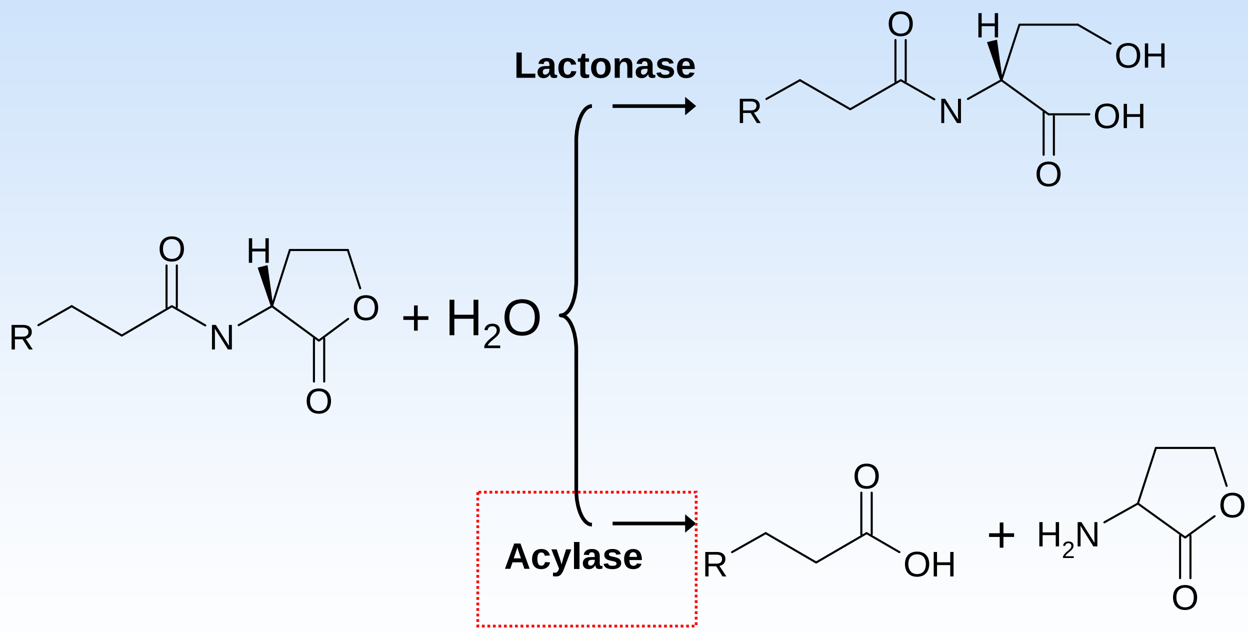
Phase 3

How to control QS in MBR:

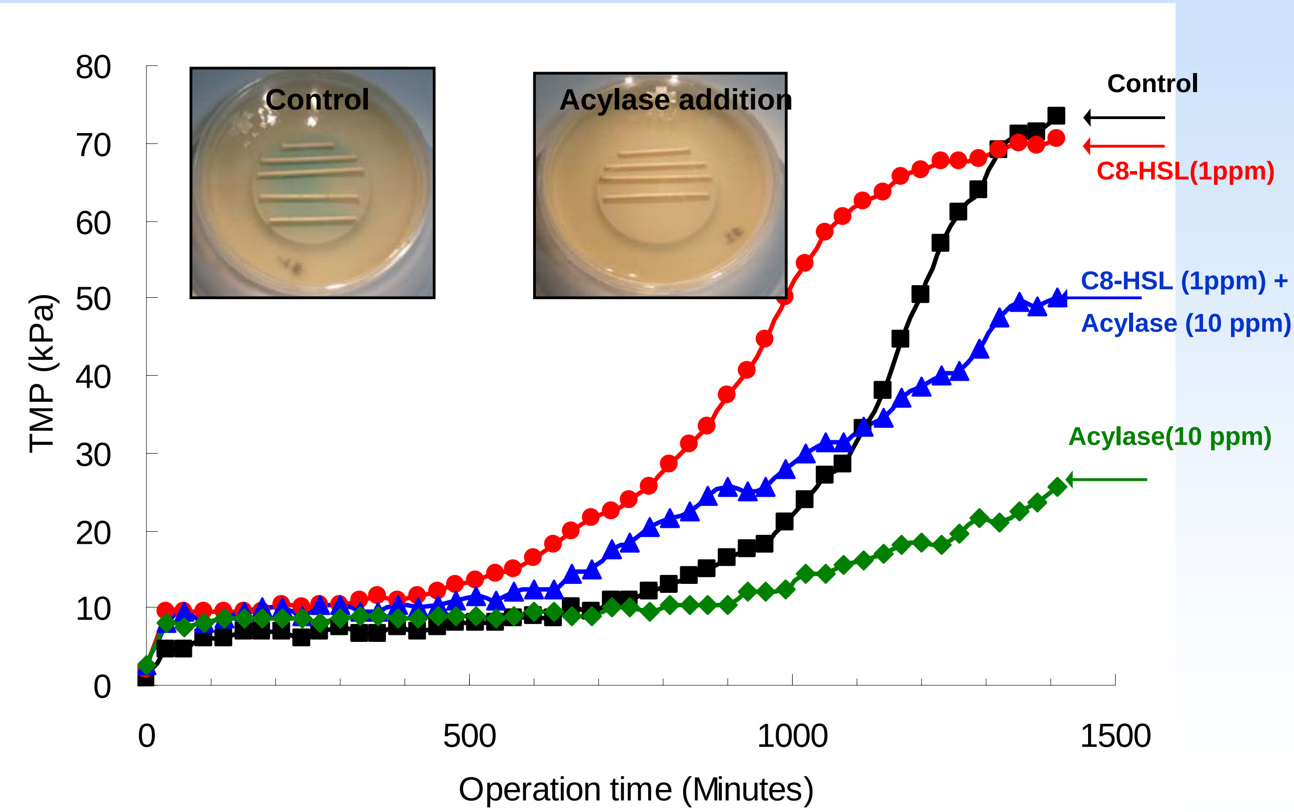
Quorum Quenching

Quorum quenching

- *Definition;* **Destruction of autoinducer by an enzyme**



Biofouling prevention by quorum quenching

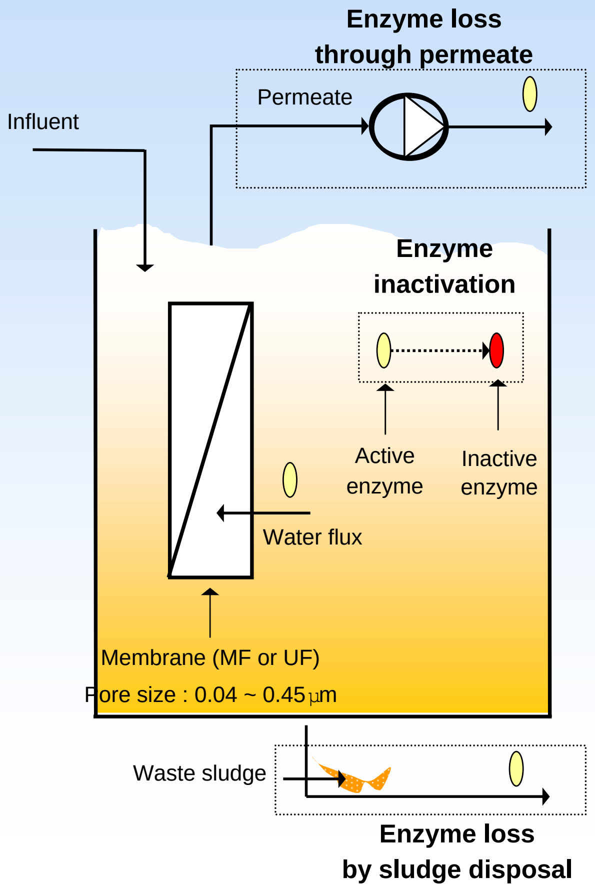


Phase 4

Practical application of Quorum Quenching:

Problems and solutions

Loss of soluble acylase in continuous MBR operation

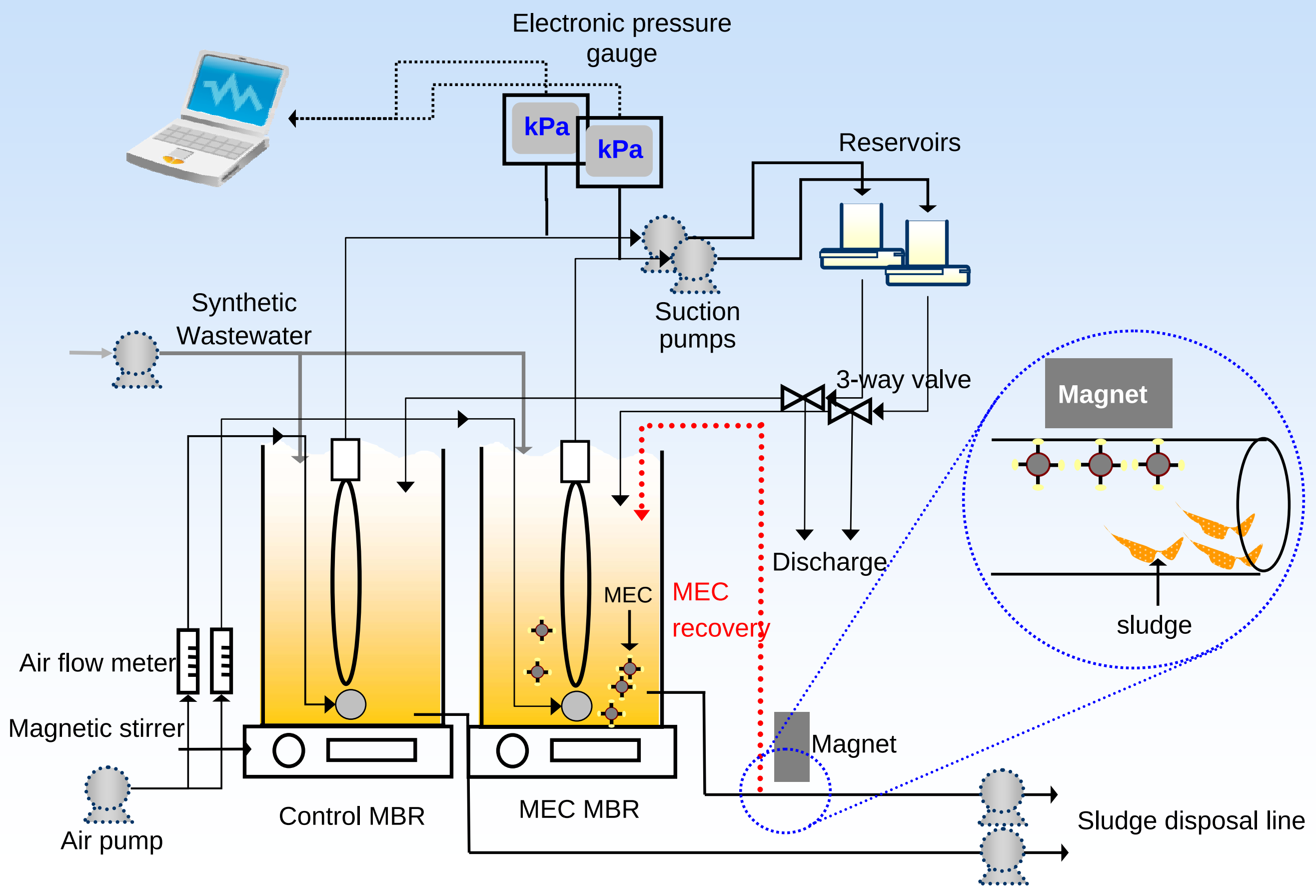


How to apply quorum quenching enzyme to MBR in continuous operation ?

⇩

Magnetic Enzyme Carrier (MEC)

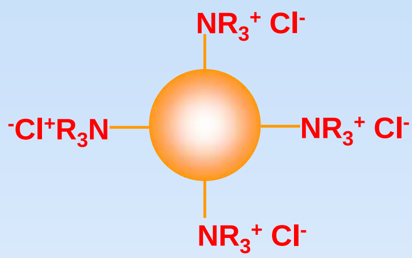
Schematic diagram of MBR in continuous operation



Preparation of Magnetic Enzyme Carrier

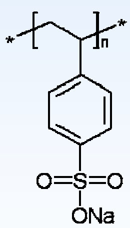
- **Magnetic core**

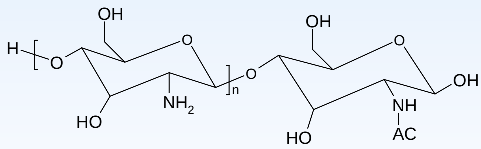
  Magnetic ion exchange resin (MIEX)



- **Immobilization layer**

  Poly(sodium-4-styrenesulfonate) (PSS) Poly(D-glucosamine) deacetylated chitin (chitosan)

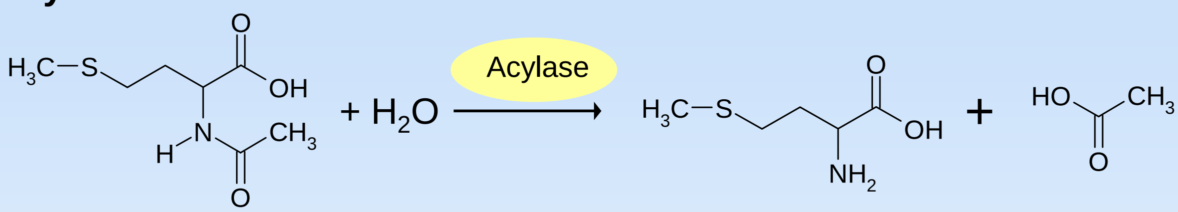




- **Enzyme**：Acylse (EC Number 3.5.1.14)

Enzymatic stability of MEC : Scheme

Enzyme reaction



N-acetyl-L-methionine (λ_{max}=238 nm) L-methionine Acetic acid

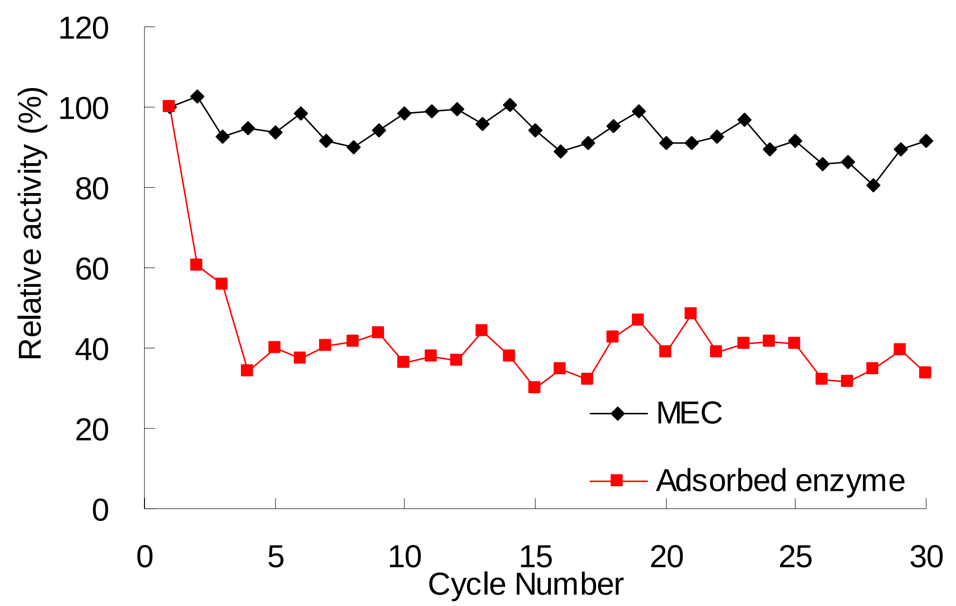
Definition of the terms

- Activity = slope of A238 with time
- Initial activity = activity measured in the 1st run or at time 0
- Residual activity = activity measured in the nth run or at time t
- Relative activity (%) = $\frac{\text{Residual activity}}{\text{Initial activity}} \times 100$ → Indicator of the enzyme stability

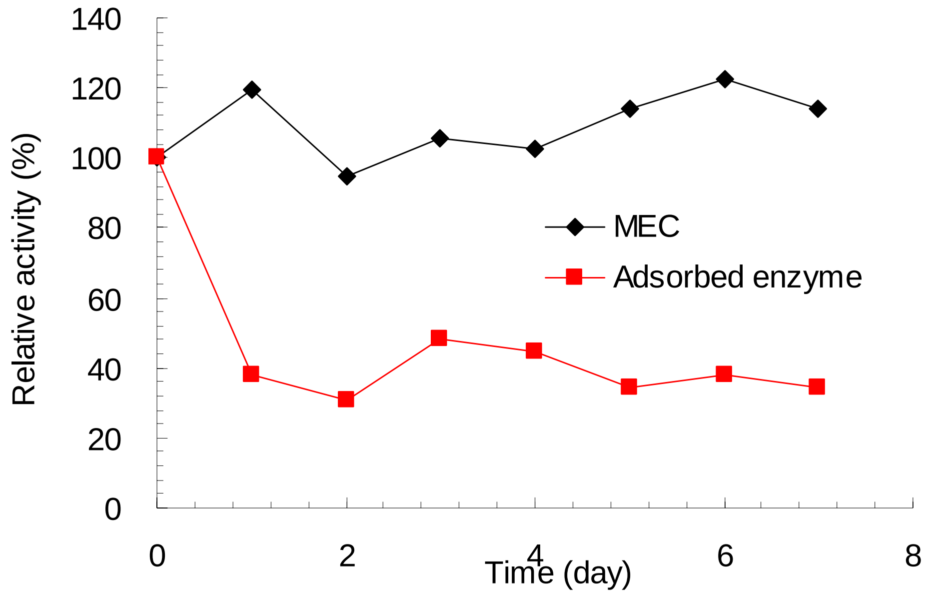
Methods

- Iterative cycle experiment
- Continuous shaking experiment

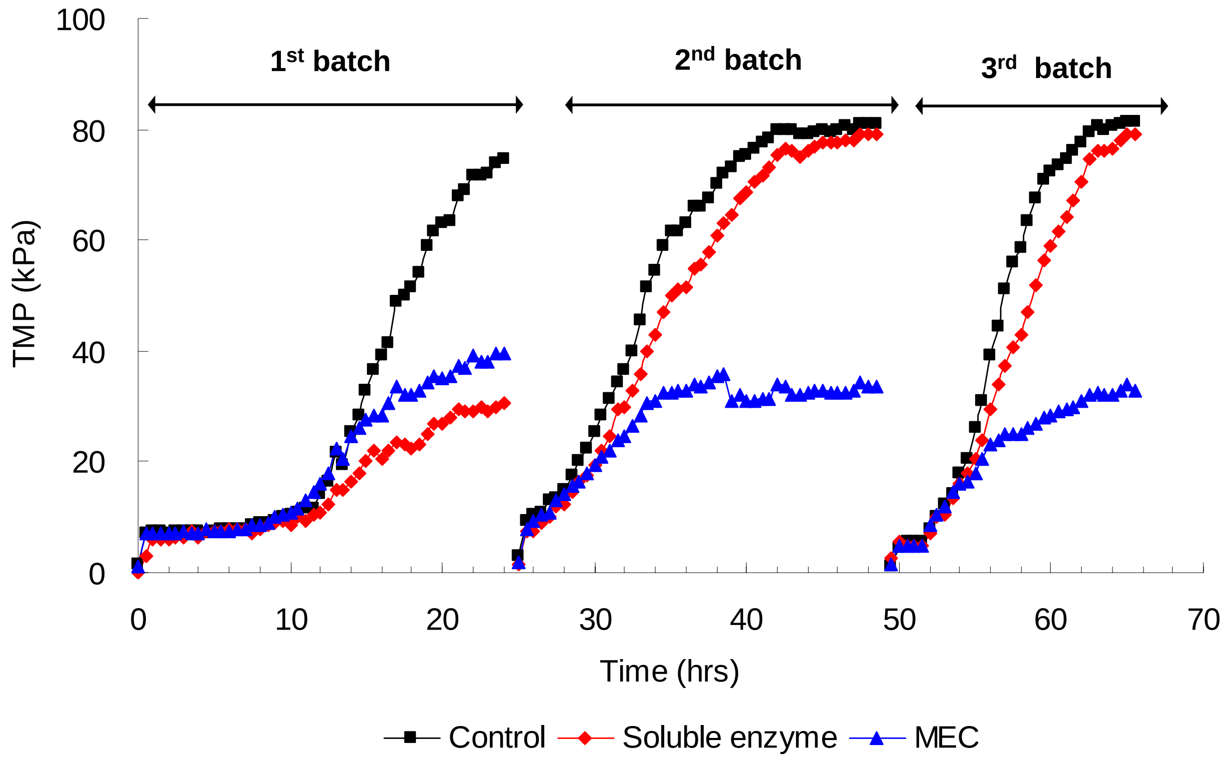
Iterative cyclic experiment



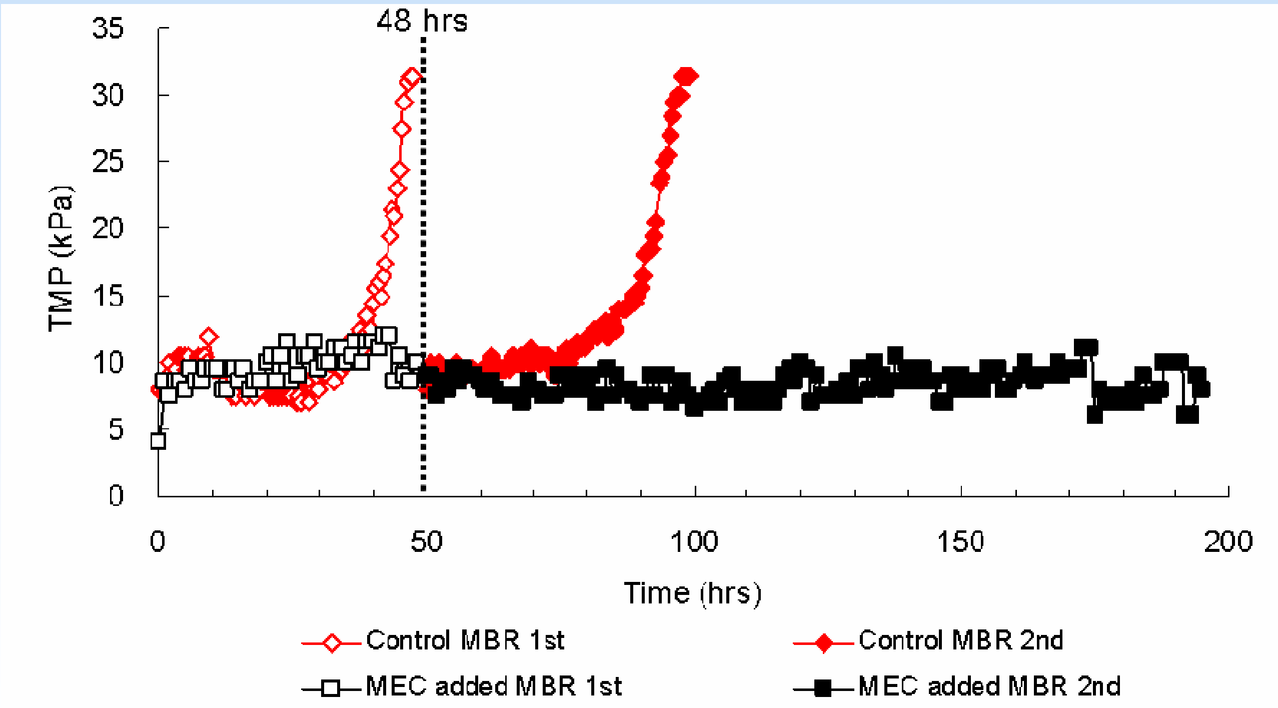
Continuous shaking experiment



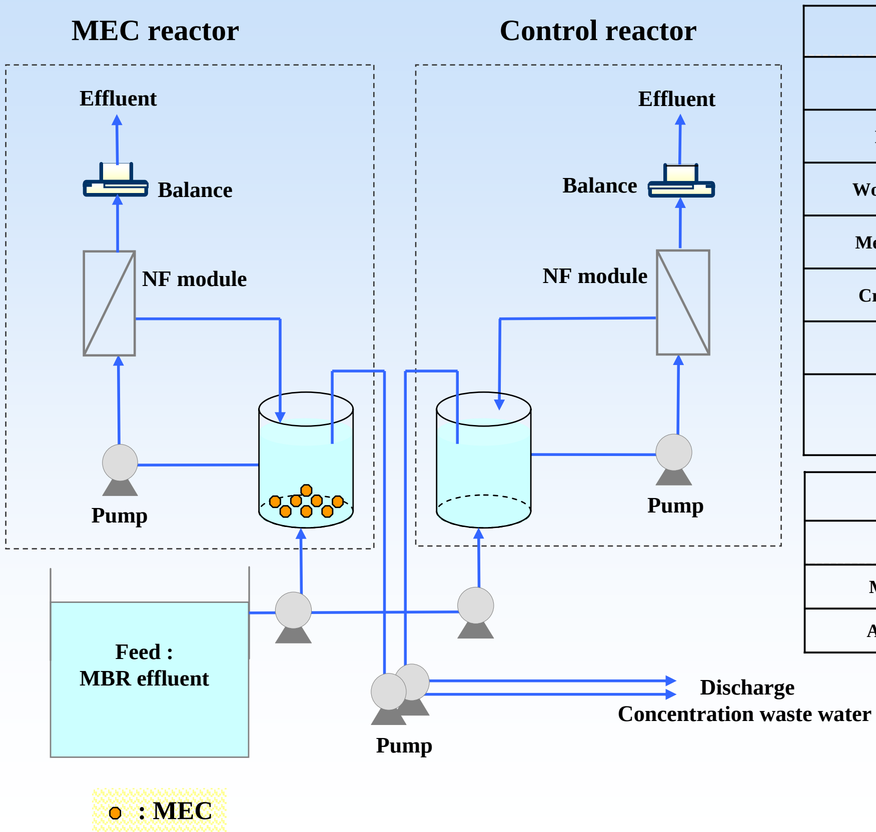
Magnetic enzyme carrier vs Soluble acylase



Effect of MEC on MBR performance: TMP profile



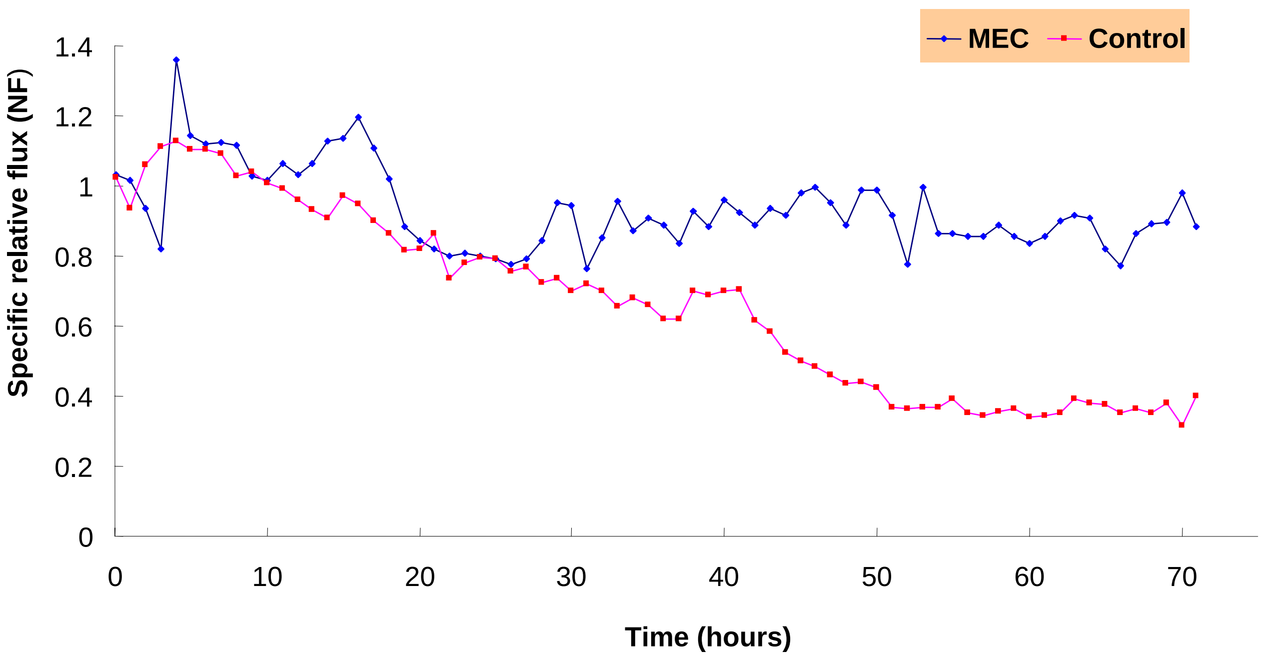
Effect of MEC on Nanofiltration of MBR effluent



Operating conditions	
Pressure	3.3 ~ 3.6 bar
Membrane	NF (Woongjin)
Working volume	1 L
Membrane area	0.0025 m^2
Cross flow rate	100 ml/min
Feed COD	20 ~ 40 mg/L
Discharge flow rate	2.0 ml/min

MEC reactor	
MEC size	100 ~ 200
MEC dosage	1.0 g
Acylase conc.	9.05 mg/L

Effect of MEC on Nanofiltration in crossflow operation



Conclusions

Quorum Sensing :

It opens a new horizon to the biofouling control in MBRs.

Acknowledgements

Thank You!

Chung-Hak Lee, **K.M. Yeon, S.Y. Kim, J.H. Kim**

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