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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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Final MBR-network workshop, Berlin, Germany
March 31 – April 1, 2009

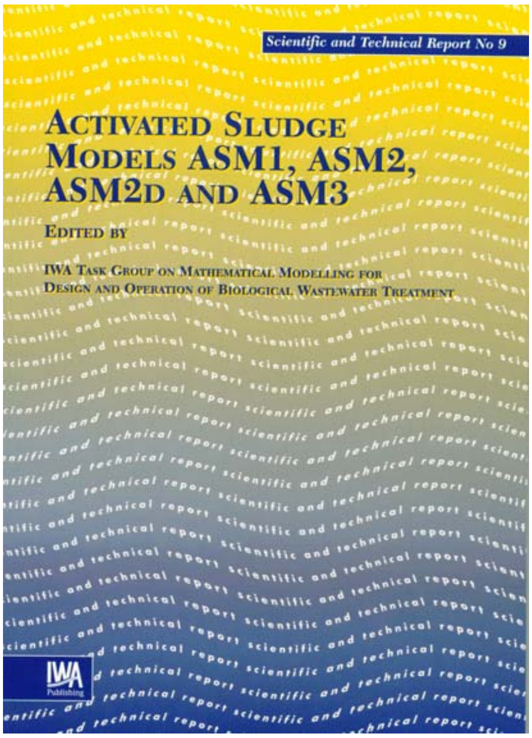
A real MBR-network effort...

- AMEDEUS
  - Aquafin (J. Roels)
  - Anjou Recherche (J. Jimenez)
  - KWB (B. Lesjean)
- EUROMBRA
  - Trento Univ (G. Guglielmi, D. Saroj)
  - INSA Toulouse (M. Sperandio)
- MBR-TRAIN
  - Ghent University (I. Nopens)
  - KWB (B. Lesjean)
  - Aquafin (A. Fenu, J. Roels)

- Initiative launched within Liaison Group on (biological) modelling of MBR

Short intro to Activated Sludge Models (ASM)

- ASM1
  - Nomenclature: X and S
  - Focus on sludge production, oxygen consumption and N-removal
  - COD-based
  - Petersen/Gujer matrix
- ASM2(d)
  - Bio-P removal
- ASM3
  - Storage and endogenous respiration instead of death-regeneration


Scientific and Technical Report No 9

ACTIVATED SLUDGE MODELS ASM1, ASM2, ASM2D AND ASM3

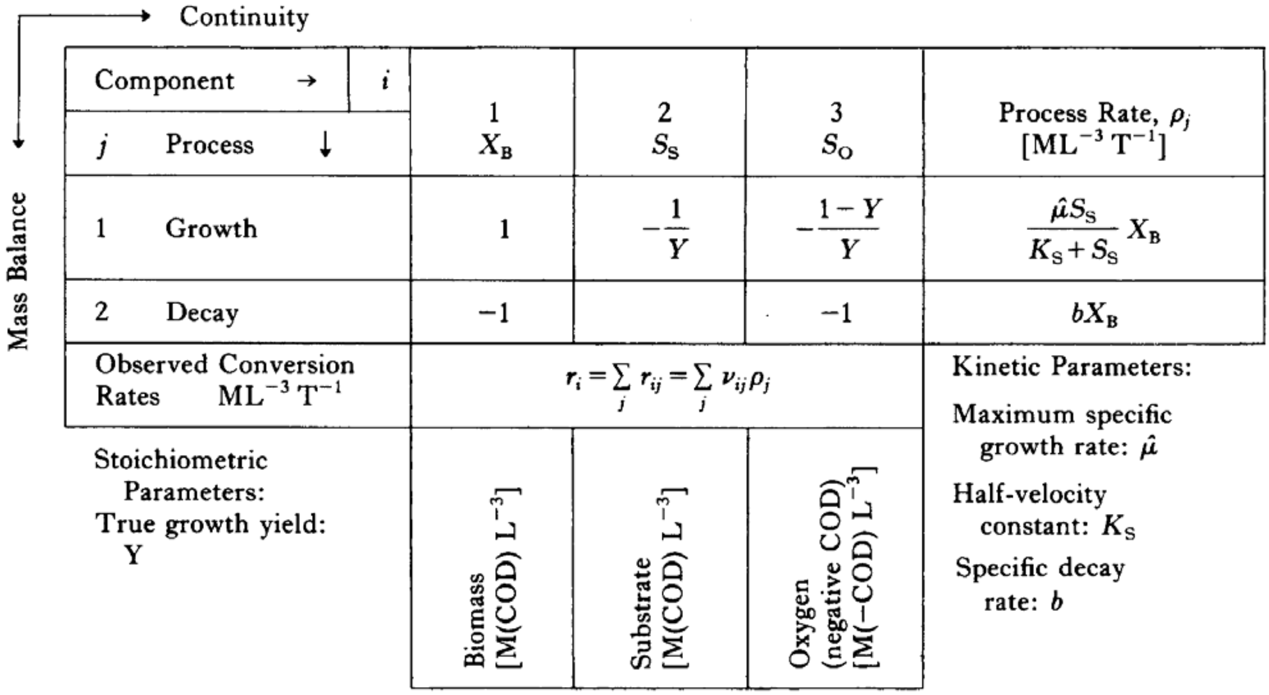
EDITED BY

IWA TASK GROUP ON MATHEMATICAL MODELLING FOR DESIGN AND OPERATION OF BIOLOGICAL WASTEWATER TREATMENT

IWA Publishing

Short intro to Activated Sludge Models (ASM)

Petersen/Gujer matrix



Component → i j Process ↓	1 X_B	2 S_S	3 S_O	Process Rate, ρ_j $[ML^{-3}T^{-1}]$
1 Growth	1	$-\frac{1}{Y}$	$-\frac{1-Y}{Y}$	$\frac{\hat{\mu}S_S}{K_S+S_S}X_B$
2 Decay	-1		-1	bX_B
Observed Conversion Rates $ML^{-3}T^{-1}$	$r_i=\sum_j r_{ij}=\sum_j \nu_{ij}\rho_j$			Kinetic Parameters: Maximum specific growth rate: $\hat{\mu}$ Half-velocity constant: K_S Specific decay rate: b
Stoichiometric Parameters: True growth yield: Y	Biomass $[M(COD)\,L^{-3}]$	Substrate $[M(COD)\,L^{-3}]$	Oxygen (negative COD) $[M(-COD)\,L^{-3}]$	

Biological modelling of MBR

- Can we just reuse and apply these models for MBR?
- A lot of research done on the topic, but scattered in literature
- Goal: provide a review with respect to
  - Validity of fundamental concepts of ASM in MBR context
  - COD fractionation
  - Bio-kinetic parameters
  - Integration of SMP/EPS concepts
- Niches for further research

Relevance of fundamental concepts of ASM with respect to MBR

- Fundamentals of ASP are valid for MBRs
- Operational differences
  - Higher SRT: impacts sludge production
    → debate on the better model to use, ASM1/ASM3
  - Retention of colloidal material: impacts autotrophic kinetics
- Trend: slight *model structure* modifications aiming at better description in MBR biological process dynamics

COD fractionation

- In ASMs the output is highly influenced by input COD fractions (impact on effluent COD, oxygen requirement, sludge production, etc)
- Experimental fractionation is usually carried out with batch tests (i.e. respirometric techniques) or mathematical calibration of COD fractions by fitting the long term MLSS dynamics
- Recent developments in combining physical (particle size distribution), chemical (coagulation/flocculation) and biological (respirometry)

COD fractionation in MBR modelling: open issues and research needs

- SRT ≤ 30 days (large centralised installations): experimental COD fractionation is suitable for ASMx calibration
- SRT ≥ 50 days (small decentralised plants): conventional fractionation protocols generally over-estimate sludge production
- Is “inert particulate COD” (XI) really inert?
- Fate of non-volatile solids in the feedwater
- Which fractionation effort for which user?

Differences between bio-kinetic parameters of MBRs and conventional ASP

- Differences are mainly due to :
  - (1) bio-aggregates structure which modifies diffusion and transfer of substrate (dispersed growth, flocs disaggregation, high sludge age, EPS)
  - (2) biomass microbiology and metabolic state (less floc-formers, slow-growing bacteria, high sludge age and low F/M, protozoa)
- Impact :
  - Logically: growth rate, half-saturation constants for substrate and electron acceptors
  - More controversial: hydrolysis ?, decay rates?, stoechiometry and biomass yield ?

Differences between bio-kinetic parameters of MBRs and conventional ASP

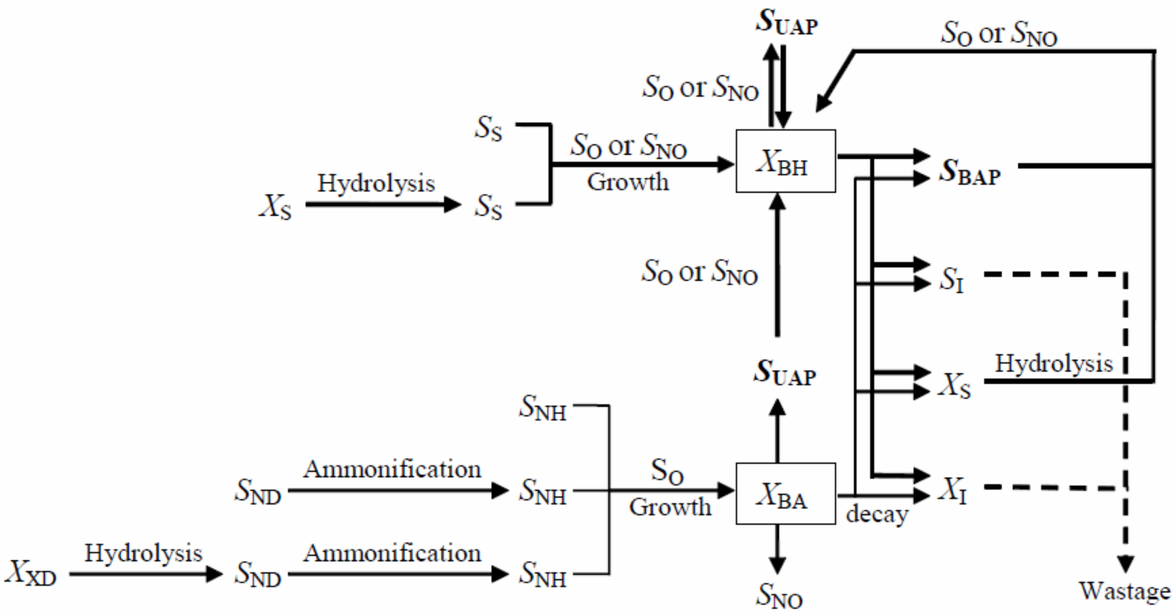
- Processes considered :
  - Nitrification (autotrophic): μa, ba, Koa
  - Denitrification (heterotrophic): Kno, Koh, ηg, ηh
  - Phosphorous removal (het-PAO)
- Objective :
  - Provide a comparative set of parameters for MBR and CAS
  - Describe the specific sensitivity of MBR simulation to parameters
  - Evaluate the missing data and information for future work on parameters identification

Integration of EPS/SMP concepts

- When is it needed? → depends on the goal of model
- Possible incentives
  - Fouling prediction – coupling with filtration model (SMP/EPS=input)
  - Better prediction of sludge water/effluent COD
  - Impact of high SRT
- How?
  - Stand-alone models for EPS/SMP
    - Adds to conceptual understanding
    - Uses different state variables than ASM
  - Integrated ASM-EPS/SMP models
    - Introduce extra states
    - Couple with existing states (new processes, process kinetics, new parameters)

Integration of EPS/SMP concepts

- Several models proposed – e.g. Lu et al.



Integration of EPS/SMP concepts

- Concept well-established/accepted
- Differences reside in
  - Process kinetics (e.g. Monod vs first order)
  - Number of parameters
- Calibration rule of thumb (identifiability)
  - Limit model complexity (# of fitting parameters) wrt available experimental data
- Either
  - Develop dedicated experiments (e.g. Jiang et al., (2009)
  - Reduce model complexity

Acknowledgement

AMEDEUS and EUROMBRA are research projects supported by the European Commission under the Sixth Framework Programme (Priority “Global Change and Ecosystems”)

Contract No. 018328 – AMEDEUS
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Duration: 01/10/05 – 31/05/09

They constitute the MBR-NETWORK Cluster
More info: www.mbr-network.eu

19. BIOLOGICAL MODELLING OF MEMBRANE BIOREACTORS AND IMPACT OF PRIMARY SEDIMENTATION

J. Jimenez, P. Grelier, A. Tazi-Pain

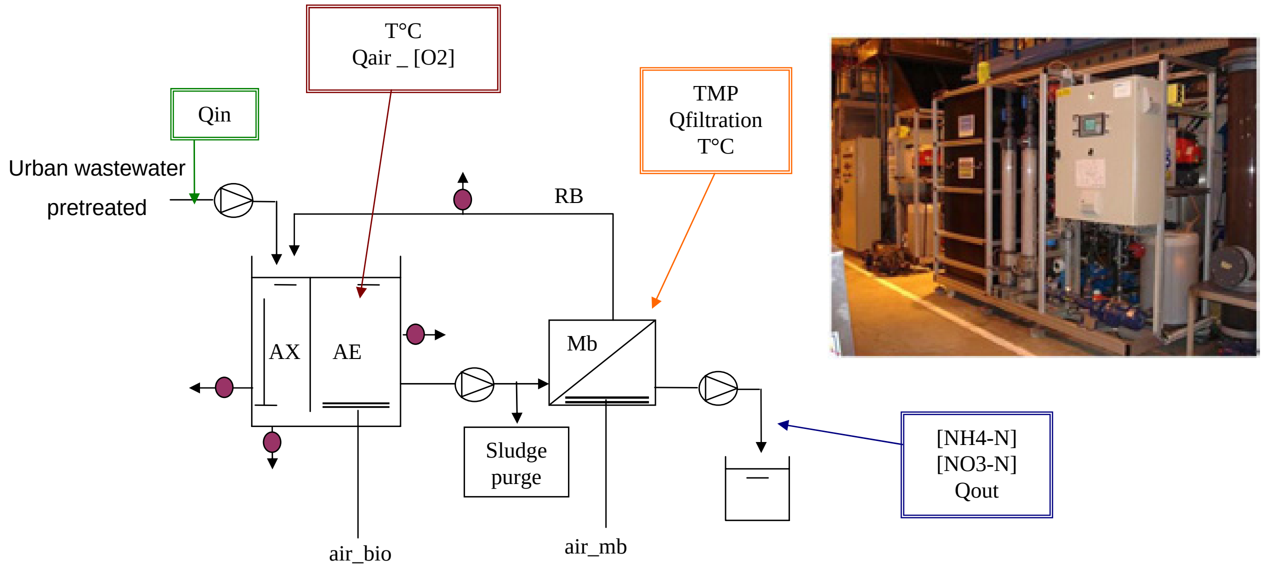
Biological modelling of MBR systems and Impact of primary sedimentation

Julie Jimenez, Patricia Grelier, Annie Tazi-Pain

WP5 Objectives

- **Biological modelling of MBR process**
  - ✓ Calibration of two pilots fed by two types of water
    - Raw water (screened)
    - Primary settled water
  - ✓ Calibration with two biological operating conditions
    - Sludge age = 15 days
    - Sludge age = 40 days
- **Impact of primary sedimentation on MBR design and operating conditions**
- **Development of Retention Time Distribution Analysis (RTDA) model**

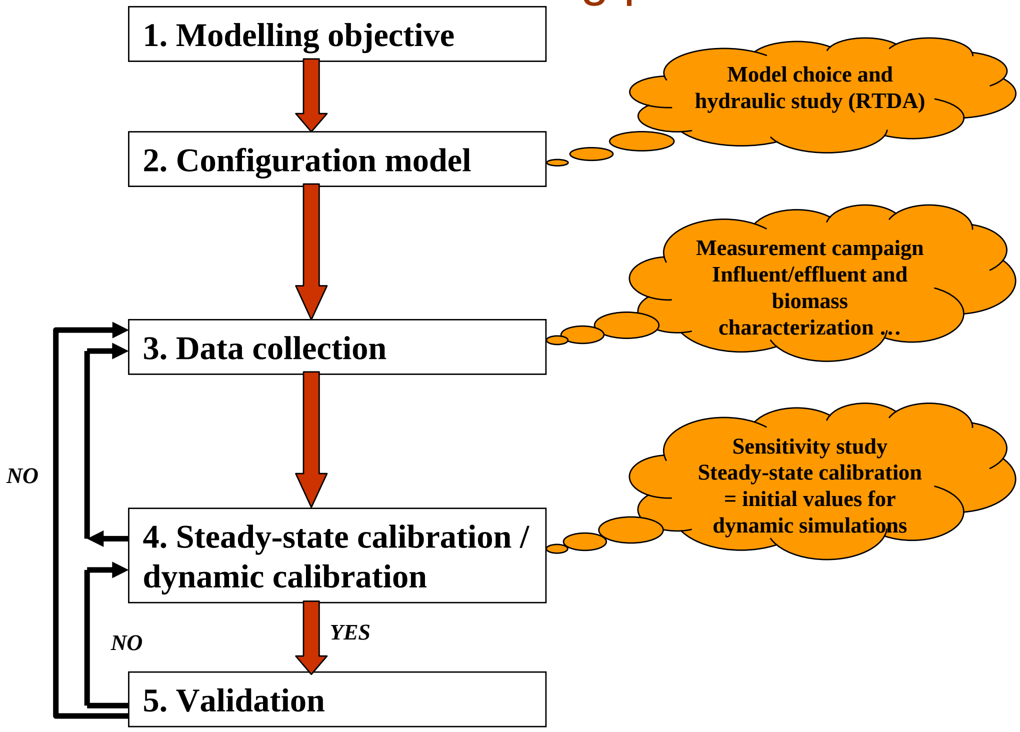
Membrane Bioreactor in AR



Operating conditions:

Sludge Retention Time : 15 & 40 days
MLSS : 6 g/l (15 d) & 10 g/L (40 d)
F/M Ratio :0,08-0,24 kg COD/kg MLSS/d
V = 795 l
Membrane: ultrafiltration POLYMEM

Modelling protocol



1. Modelling objective

2. Configuration model

Model choice and hydraulic study (RTDA)

3. Data collection

Measurement campaign Influent/effluent and biomass characterization ...

4. Steady-state calibration / dynamic calibration

Sensitivity study Steady-state calibration = initial values for dynamic simulations

YES

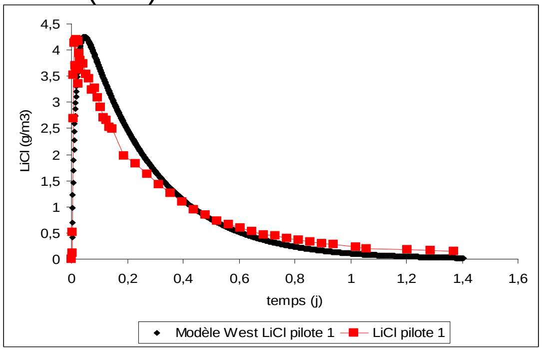
5. Validation

NO

NO

Configuration model

- ☐ Model chosen: Activated Sludge Model Anjou + perfect clarifier model
  - ➢MBR = Activated sludge biological tank+membrane
- ☐Software used: *WEST*® (MostForWater, Belgium)
- ☐Configuration data collection
  - ➢ Volumes, flow rates, anoxic zone, aerobic zones, etc…
- ☐Systemic representation validation
  - ➢WEST configuration: CSTR: Comparison between experimental data and tracer test simulation (LiCl)



Results: wastewater characterization

	tCOD	fCOD	TSS	VSS/TSS	TAC	NH_4^+	TKN
	g/m³	*g/m³*	*g/m³*	*g/m³*	*g/m³*	*g/m³*	*g/m³*
Raw water	**607**	**150**	**280**	**72%**		**45**	**55**
Settled water	**430**	**148**	**151**	**73%**	**380**	**44**	**58**
Minimum	*346*	*121*	*104*	*66%*	*340*	*40*	*110*
Maximum	*610*	*183*	*211*	*83%*	*390*	*55*	*49*
Settler efficiency	*24%*		*46%*				
Screened water	**513**	**147**	**233**	**77%**	**390**	**45**	**53**
Minimum	*444*	*126*	*189*	*68%*	*370*	*41*	*467*
Maximum	*613*	*169*	*277*	*88%*	*400*	*49*	*61*
Screen efficiency	*15%*		*17%*				
Difference Screen / Settler	**16%**		**35%**				

ASM fractionation

	Settled water		Screened water		ASM1
	mg COD/l	*% COD*	*mg COD/l*	*%COD*	*%COD*
Ss Readily biodegradable fraction	86	33%	86	18%	25%
Xs Slowly biodegradable fraction	99	38%	284	58%	50%
Si Inert soluble fraction	38	15%	36	7%	10%
Xi Particular inert fraction	**37**	**14%**	**80**	**16%**	**15%**

Results: operating conditions

SRT	Pilot	Load	Y_{obs}	MLCOD	MLSS	%MLVSS
days		*kg COD /m^3.d*	*g MLVSS / g COD*	*g/m^3*	*g/m^3*	*g/m^3*
15	Settled pilot	1,25	0,18	6025	5533	69%
15	Screened pilot	1,20	0,22	6002	5142	77%
	Difference		**22%**	**1,2%**	**7%**	**12%**
40	Settled pilot	0,69	0,21	9255	9231	67%
40	Screened pilot	0,76	0,15	9590	8963	71%
	Difference		**29%**	**4%**	**3%**	**6%**

- Main results:
  - Sludge production lower for settled pilot
  - Sludge production reduction with the increase of SRT but not for settled pilot…

Model calibration results

			SRT 15 days		SRT 40 days	
Variables calibrated	Calibration parameters	Default model	Pilot settled	Pilot screened	Pilot settled	Pilot screened
MLCOD	**Influent fraction X_I**	**25%**	**18%**	**22%**	**25%**	**12%**
MLISS	ISS (solubilisable fraction/rate)	(0,5;0,03)	(0,5;0,03)	(0,6;0,03)	(0,5;0,08)	(0,9;0,08)
MLVSS	COD/VSS inert fraction	1,2	0,7	0,7	0,25	0,6
COD out	**Influent fraction S_I**	**15%**	**9%**	**9%**	**9%**	**9%**
NH4+ out	**(μ_A, b_A) (d^{-1})** **$K_{OA}(g/m^3)$**	**(0,85;0,15)** **0,5**	**(0,85;0,15)** **0,3**	**(0,85;0,15)** **0,25**	**(0,85;0,10)**	**(1;0,15)**
NO3- out	K_{OH} (g/m^3)	0,2	**0,1**	**0,1**	0,05	0,01

Different parameters calibration: model limits

Dynamic simulations at 15 d (1)

Settled pilot

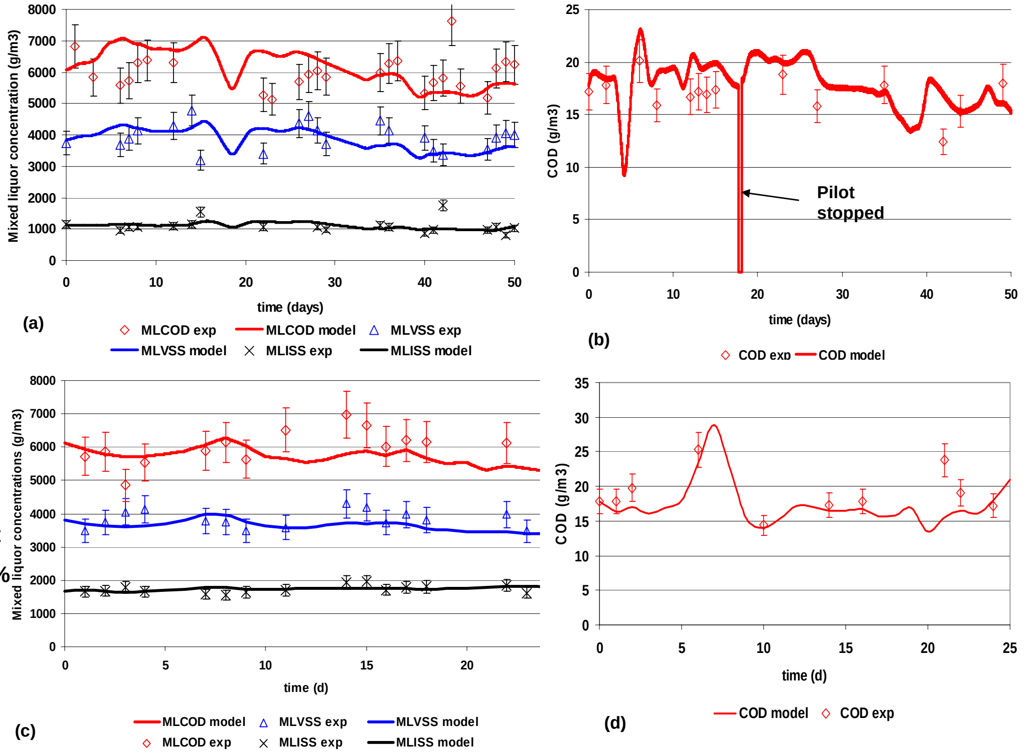
MLSS, COD out

Deviation 10%

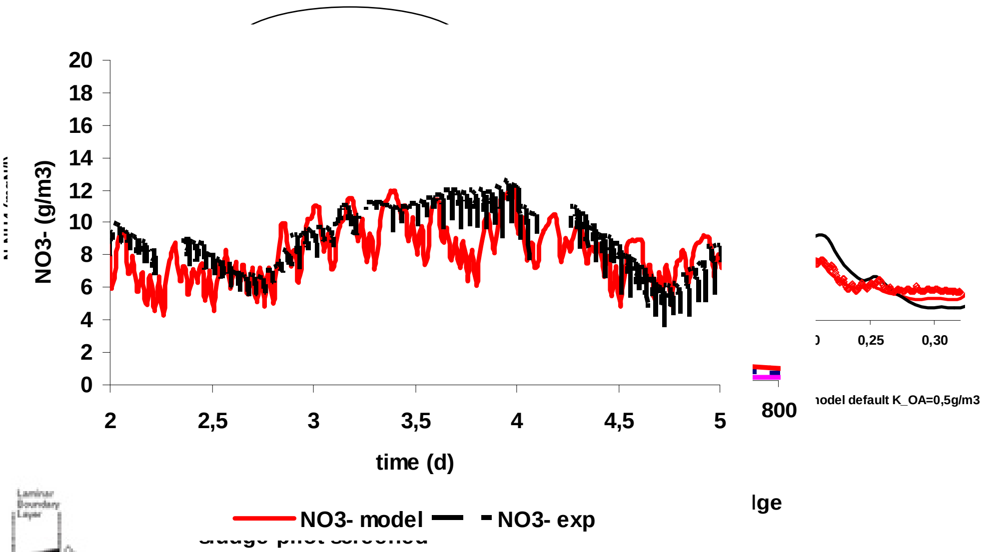
Screened pilot

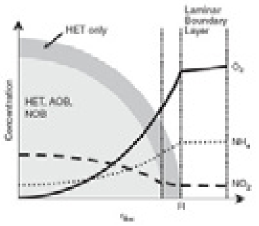
MLSS, COD out

Deviation 10-11%



Dynamic simulations at 15 d (2)





S_NH calibration: decrease K_{OA} to 0,25-0,3 g/m^3

S_NO calibration: decrease K_{OH} to 0,1 g/m^3

Manser, Gujer, Siegrist, 2005: oxygen transfer linked with floc size distribution; small flocs→ diffusion resistance negligible (internal K)

Oxygen inhibition on denitrification higher…

→can work with dissolved oxygen lower than CAS: aeration cost decreases

Negative effect of small flocs: dissolved oxygen return from membrane tank: → difficulties on denitrification calibration

Discussion

Calibration 15d:

- X_I fraction lower in settled influent: lower biological sludge production
- Kinetical parameters:
  - Nitrification: better oxygen uptake by nitrifiers due to small floc sizes
  - Denitrification: negative effect of the sludge recirculation in anoxic zone and of the small flocs
    - → Oxygen inhibition more important than CAS
- Floc size distribution : depends on process configuration, pump, aeration and turbulence generated by them

Calibration 40d:

- SRT increases: accumulation of X_I+Xp (inert) until a limit where begins the biomass acclimatation and biodegradation of these molecules (SMP&EPS) *(Espinosa, 2005; Massé, 2006)*
  - Screened pilot: biodegradation of X_I (as others authors) because of biomass acclimatizing
  - Settled pilot: biomass not acclimated and accumulation of inert because of low extraction flow
- Model reach its limits when SRT increase: SMP and EPS biodegradation modelling (Jiang, 2006)

Comparison: screen vs settler (1)

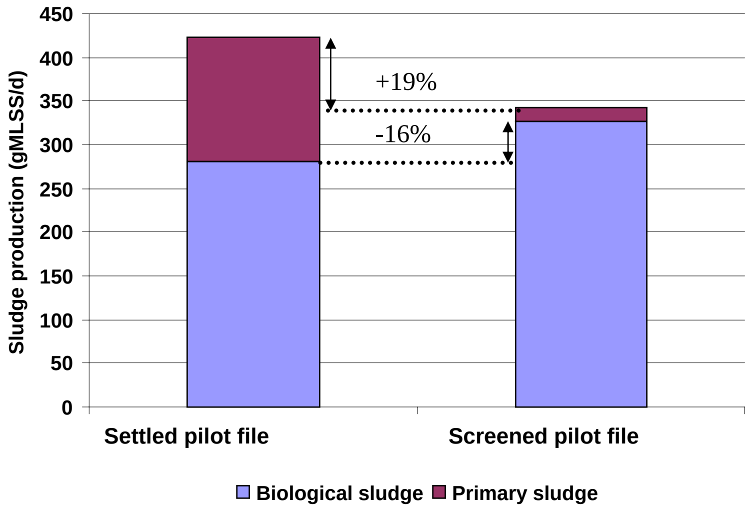
Impact of the screened wastewater on the membrane

The membranes were observed under binocular lup

- many marks visible on the membrane of screened pilot
- But no differences on hydraulic performances

Comparison: screen vs settler (2)

- Sludge production calculation: balance made at SRT 15d
    - Biological tank
    - The entire file (primary sludge + biological sludge): more particular matter retained in settler



Perspectives….

- **Interest of settler: sludge treatment by anaerobic digestion**
    - More sludge produced in file “sedimentation”…
    - But primary sludge bring supplementary biodegradable matter
    - Sludge from file “settler”: less inerts fractions
    - the file “sedimentation” can bring a better quality of biogas, despite of the higher amount of sludge produced
    - Simulations of Biological Methane Potential tests ongoing…

Acknowledgement

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20. TECHNICAL FEASIBILITY AND OPTIMAL CONTROL STRATEGY OF DUAL (HYBRID) MBR-CAS CONCEPTS FOR PLANT REFURBISHMENT

W. De Wilde, K. Moons, D. Bixio, C. Thoeye, G. De Gueldre

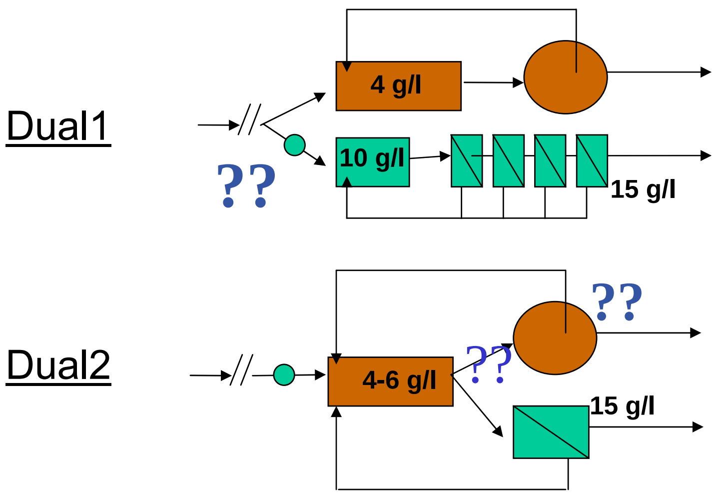
Technical Feasibility and Optimal Control Strategy of Dual (hybrid) MBR-CAS Concepts for Plant Refurbishment

Chris Thoeye, Lucas Maes, Wouter de Wilde
Davide Bixio, Kathleen Moons
Greet De Gueldre

- **Established** in 1990
- **Mission**: to finance, design, construct, operate supra-municipal infrastructure in the Flemish Region
  - 6,000,000 inhabitants
  - 200+ sewer catchments
- **Modelling**:
  - in the last 10 years renovated 100+ plants to nutrient removal, > 20 have been renovated based on advanced modelling techniques
  - now mainly used for operational optimisation
- **MBR**: first full-scale MBR for municipal wastewater in BENELUX,
  - Patent on design and operation of DUAL CAS-MBR system

WP OBJECTIVES

- ‚Dual' technology (= MBR-CAS hybrid)



Flow distribution ?

Flow distribution ?

Settleability ?

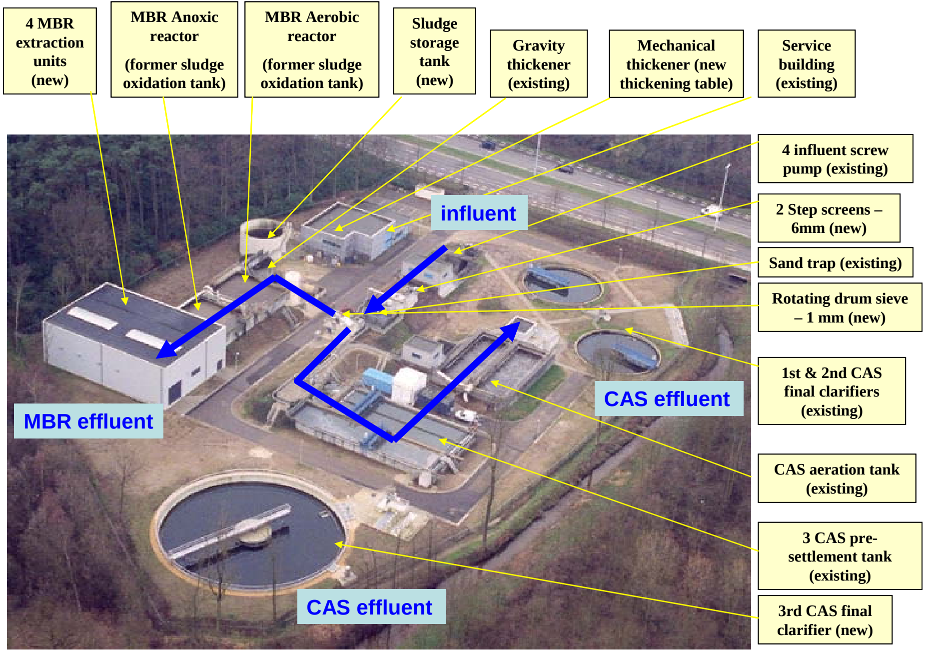
What do we want to know ?

- **Task 9.1:**

- **Optimised control strategy of influent split for MBR/CAS Dual 1 concept**

- What is the optimal splitter control ?
- Does it work ?

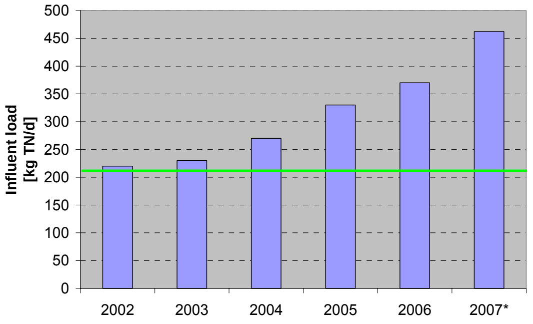
Dual 1 concept at WWTP Schilde



- *De Wilde et al. (2005)* Operational experiences and optimisations two years after start-up of the first full-scale MBR for domestic wastewater treatment in the Benelux.
- *Garcés et al (2007)* Operational cost optimisation of MBR Schilde.

Key facts DUAL 1 Schilde

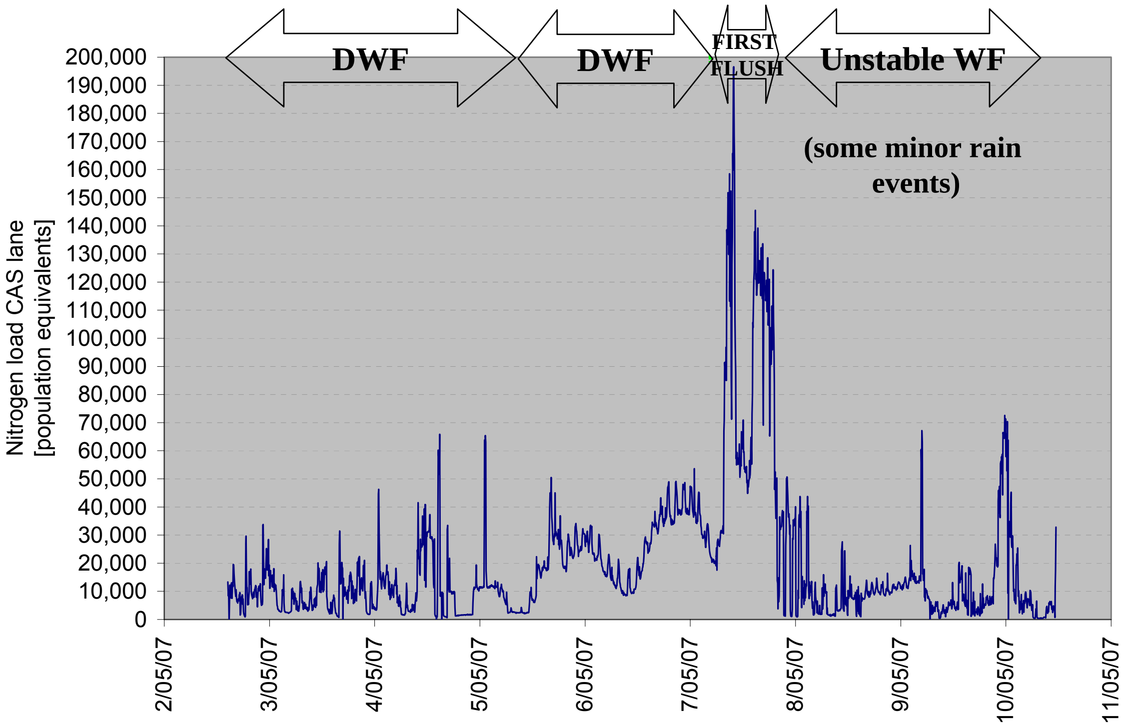
- From 18,000 to 28,000 inhabitants
- Nominal capacity: 207 kg N/d
- Hydraulic capacity: 1836 m³/h (6 Q_{14} i.e. ±10 DWF)



- Heavily overloaded (>80%)
- Heavy first flush events
- New consents since 1 Jan 2006
    - Yearly % removal
    - Daily maxima

	Yearly basis	Daily max	Eff.*
	[mg/l]	[mg/l]	[%]
BOD	25	50	90%
COD	125	250	75%
SS	35	88	90%
TN	15	20	50%
TP	2	-	80%

Important first flush events



How did we proceed ?

- Model MBR Schilde building in the WEST-software environment
- Sludge characterisation tests (Maximum autotrophic growth rate, Autotrophic decay rate, Affinity constant for ammonia, presence and quantification of poly-phoshate accumulating organims)
- Calibration and validation of the baseline operation of WWTP Schilde
- Model-based analysis of a number of flow repartition control strategies (FRCS)
- Definition + discussion + approval of the feedforward/feedback control algorithm, fine-tuning and implementation into the PLC
- First evaluation phase of the new control of the Dual 1 concept finished

---

The CAS/MBR model is capable of describing the complex behaviour of the WWTP

MBR	**Units**	**Observations**	**Simulation**	
MLSS_{AER}	g/l	**10.6**	**10.5**	✓
COD_{EFF}	mg/l	**24**	**24**	✓
BOD_{EFF}	mg/l	**<1.2**	**0.25**	✓
SS_{EFF}	mg/l	**0**	**0**	✓
$\text{NH}_4\text{-N}_{\text{EFF}}$	mg/l	**0.1**	**0.1**	✓
$\text{NO}_x\text{-N}_{\text{EFF}}$	mg/l	**7.2**	**6.8**	✓
TN_{EFF}	mg/l	**7.6**	**7.2**	✓
$\text{PO}_4\text{-P}_{\text{EFF}}$	mg/l	**1.2**	**3.6**	✗
TP_{EFF}	mg/l	**1.3**	**3.7**	✗

CAS	**Units**	**Observations**	**Simulation**	
MLSS_{AER}	g/l	**3.5**	**3.7**	✓
MLSS_{RAS}	g/l	**5.6**	**5.4**	✓
COD_{EFF}	mg/l	**44**	**35**	✓
BOD_{EFF}	mg/l	**4.0**	**2.5**	✓
SS_{EFF}	mg/l	**9.2**	**8.9**	✓
$\text{NH}_4\text{-N}_{\text{EFF}}$	mg/l	**1.2**	**1.5**	✓
$\text{NO}_x\text{-N}_{\text{EFF}}$	mg/l	**21.4**	**25.2**	✓
TN_{EFF}	mg/l	**23.1**	**27.3**	✓
$\text{PO}_4\text{-P}_{\text{EFF}}$	mg/l	**0.89**	**1.4**	✗
TP_{EFF}	mg/l	**1.04**	**2.4**	✗

Retained splitter control scenario

Central idea of the splitter control:

1. Maintain a minimum flow to the CAS in dry weather
2. Maintain a maximum high-flow MBR operation mode in rain weather
3. WWTP flow repartition is compared with an estimate of the MBR and CAS nitrification and denitrification capacity : required vs available

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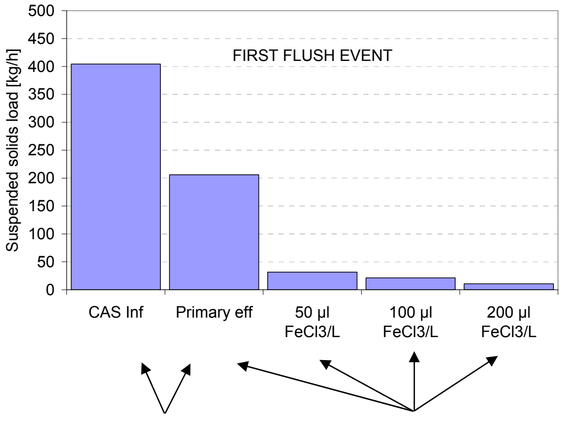
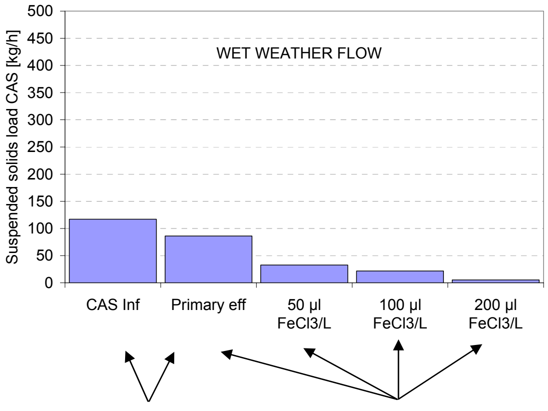
Enhanced Primary Clarification





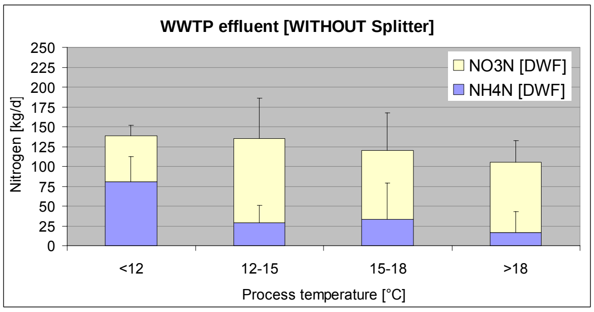
Full-scale batch tests

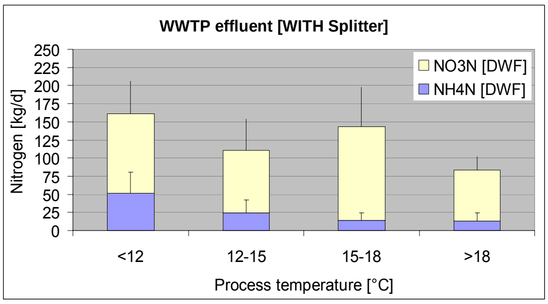
Full-scale batch tests

AMEDEUS

Conclusions : Have the effluent results improved ?

Dry weather flow – empirical results





NB TN in the WWTP influent 13% higher than for the time series of previous control strategy

- Nitrification activity can be kept into the CAS lane with a much higher degree of certainty all year round
- Online Control of intermittent aeration can lead to improved denitrification
- Enhancing the primary clarification with the dosage of iron salts is a technically viable option
- T > 12°C: 10% RE-improvement obtained, on a yearly basis

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What do we want to know ?

- **Task 9.1:**

- **Optimised control strategy of influent split for MBR/CAS Dual 1 concept**

- What is the optimal splitter control ? ☑
- Does it work ? ☑

- **Task 9.2:**

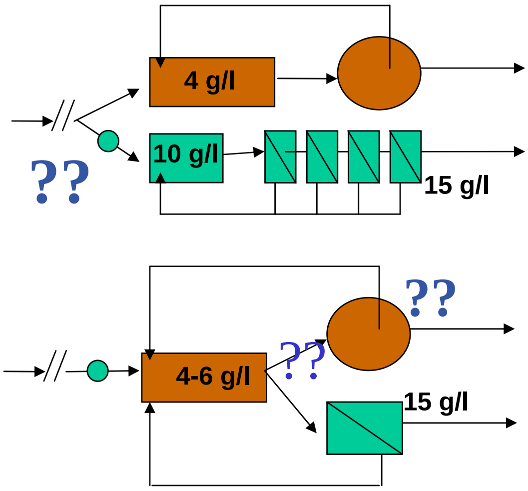
- **Pilot evaluation of design and control for MBR/CAS Dual 2 concept**

WP OBJECTIVES

- ‚Dual‘ technology (= MBR-CAS hybrid)

Dual1

Dual2

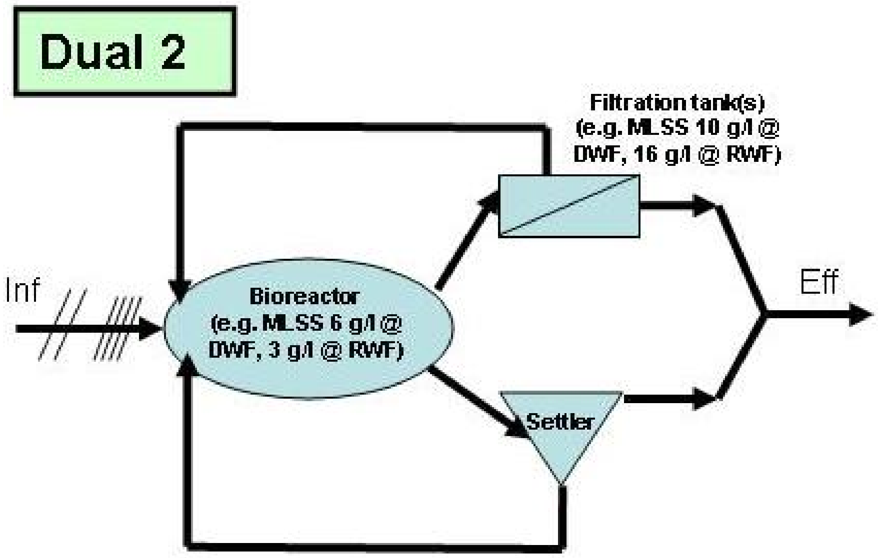


Flow distribution ?

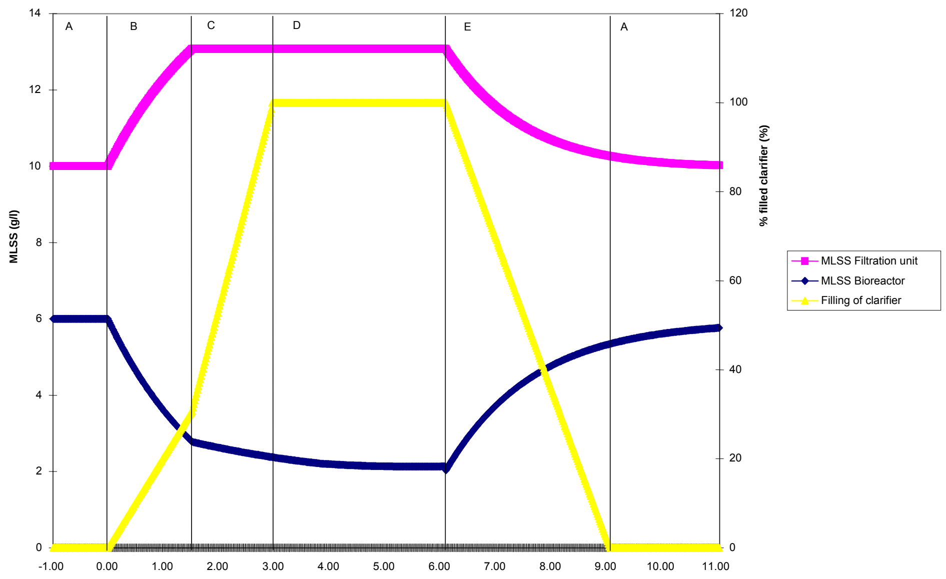
Flow distribution ?

Settleability ?

DUAL 2 Process layout



DUAL 2 Rainweather Operation

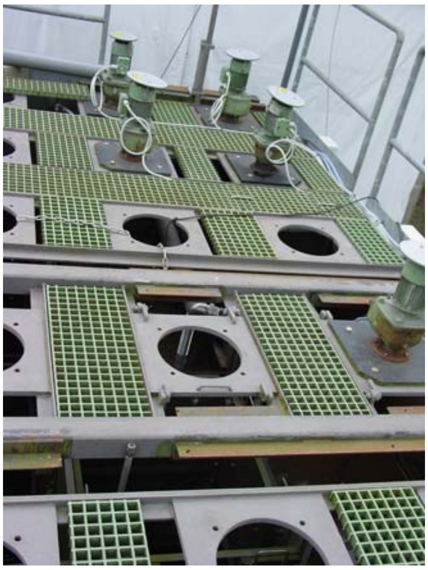


What do we want to know ?

- Task 9.2:

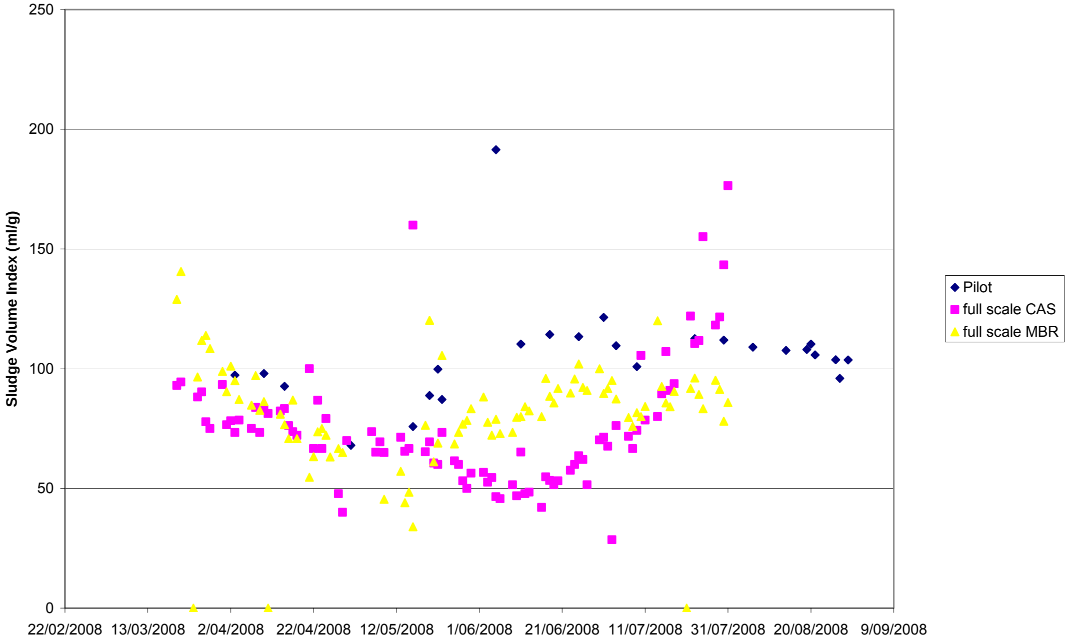
- Pilot evaluation of design and control for MBR/CAS Dual 2 concept

- How do we control the clarifier filling ?
- Does the (combined) sludge settle well ?
- Is the concept feasible ?



- Assembling and basic optimisation work of the CAS part (settlement tank)

Sludge settling ability



Dual 2 concept: conclusions

- ► On pilot scale: sludge blanket filtration leads to better effluent quality – Same effect on full scale ?

-> automation of flows necessary to control MLSS concentration

- ► Good sludge settleability retained throughout the experimental period

- ► Mixed CAS/MBR effluent quality OK

What do we want to know ?

- **Task 9.2:**

- **Pilot evaluation of design and control for MBR/CAS Dual 2 concept**

  - **How do we control the clarifier filling ?** ☑
  - **Does the (combined) sludge settle well ?** ☑
  - **Is the DUAL 2 concept feasible ?** ☑

- Validation on larger scale on-going

Thank You !

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

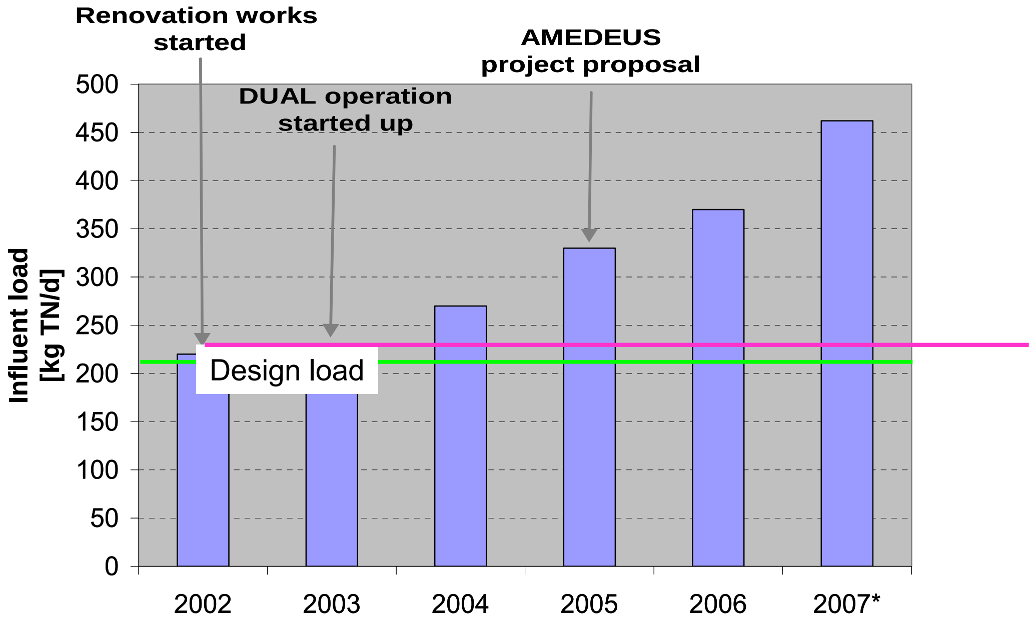
Feedforward/feedback control (1)

WWTP Inflow (m^3/h)	MBR Inflow (m^3/h)	CAS inflow (m^3/h)
0- 2*$Q_{CAS[min]}$	0.5*Q_{WWTP}	0.5*Q_{WWTP}
<($Q_{CAS[min]}$ +230)	Q_{WWTP} - $Q_{CAS[min]}$	$Q_{CAS[min]}$
<($Q_{CAS[max]}$+230)	230	Q_{WWTP}-230
>($Q_{CAS[max]}$+230)	High/low flow MBR operation	Q_{WWTP}-Q_{MBR} Fe^{3+} $_{PRIMARY\_CLARIF}$ = ƒ ($Q_{CAS[max]\ FE}$; Q_{WWTP}; Q_{CAS})

- WHERE:
  - Q_{CAS}[min] = ƒ(KjN$_{infl}$, biomass composition, Temperature, NFR, NO3-N$_{eff}$) and
  - Q_{CAS}[max] = ƒ(KjN$_{infl}$, SSinfl, QMBR, biomass comp., Temperature, NH4-N$_{eff}$, RE[TN]$_{WWTP}$)

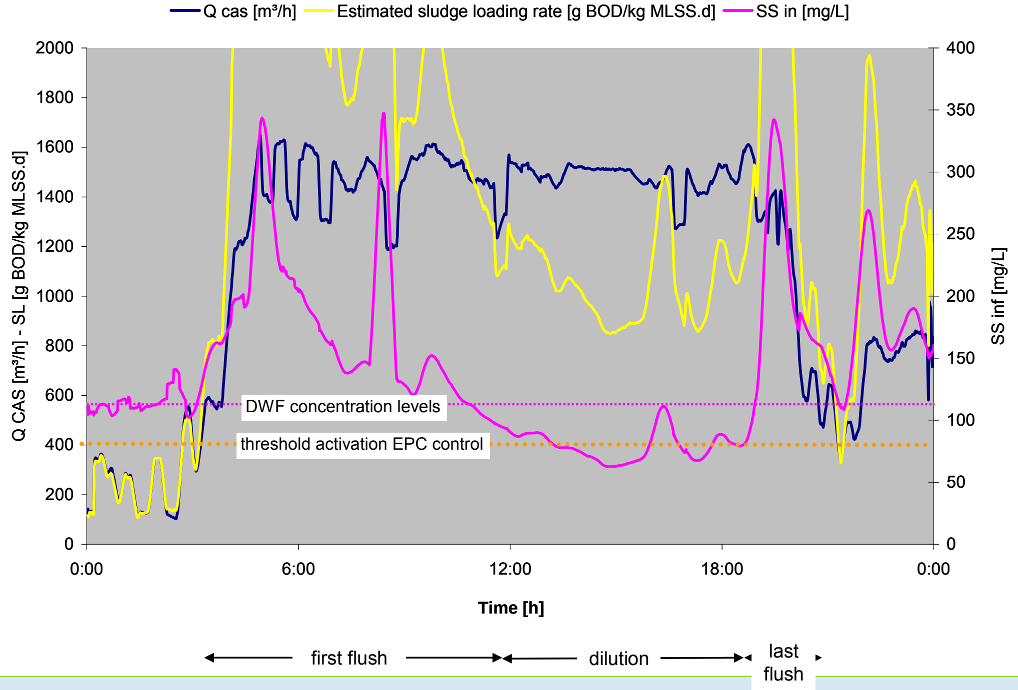
- OBJECTIVE FUNCTIONS:
  - (Q_{CAS}* RE[TN]$_{CAS}$ + Q_{MBR} * RE [TN] $_{MBR}$)/Q_{WWTP} > 50%;
  - (Q_{CAS}* c[TN]$_{CAS}$ + Q_{MBR} * c[TN] MBR)/Q_{WWTP} < 15 mg N/L;
  - c[NH4-N]$_{CAS}$ < 6 mg N/L

The extent of the WWTP overloading at Schilde



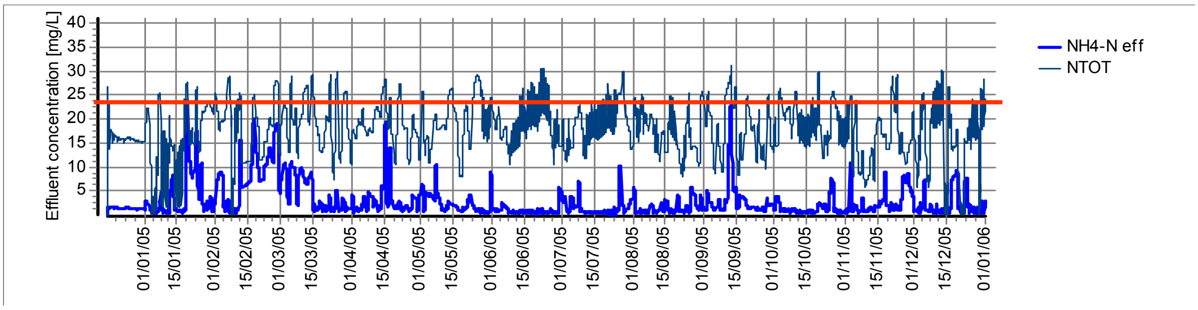
Task 9.1
Heavy first and last flush events

- SS profile in the CAS influent - typical rain event



Simulation results of the Enhanced Primary Clarification scenario

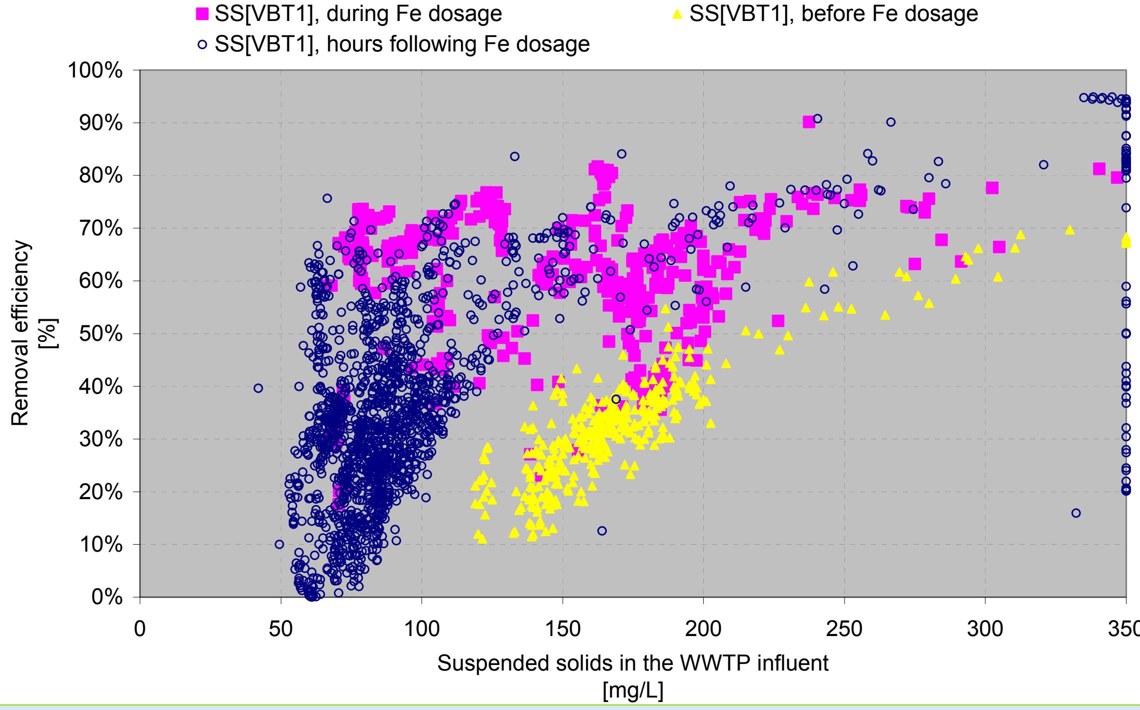
- CAS effluent results (scenario with Suspended Solids removal in the PS: 65%)



- The simulation results indicate that the problem with the daily maximum may therefore be solved (24 mg/L)

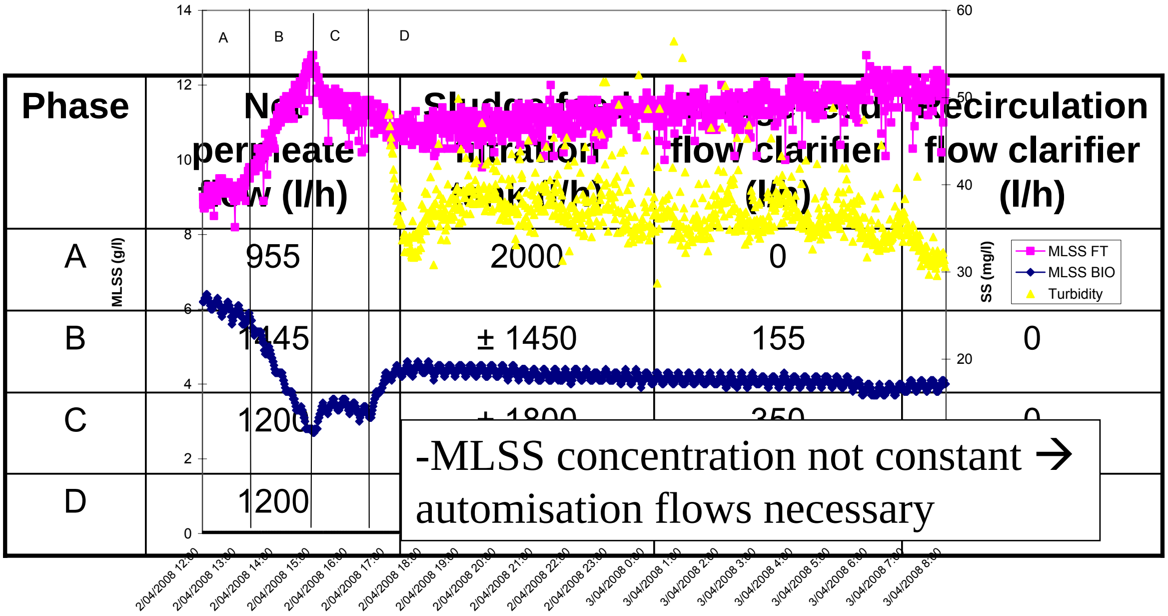
3 Have the effluent results improved ?

Fe dosing can strongly increase the SS removal efficiency



Period 3: overview tests

Test 02/04



Phase	Net permeate flow (l/h)	Sludge feed filtration tank (l/h)	Sludge feed flow clarifier (l/h)	Recirculation flow clarifier (l/h)
A	955	2000	0	
B	1445	± 1450	155	0
C	1200	± 1800	350	0
D	1200			

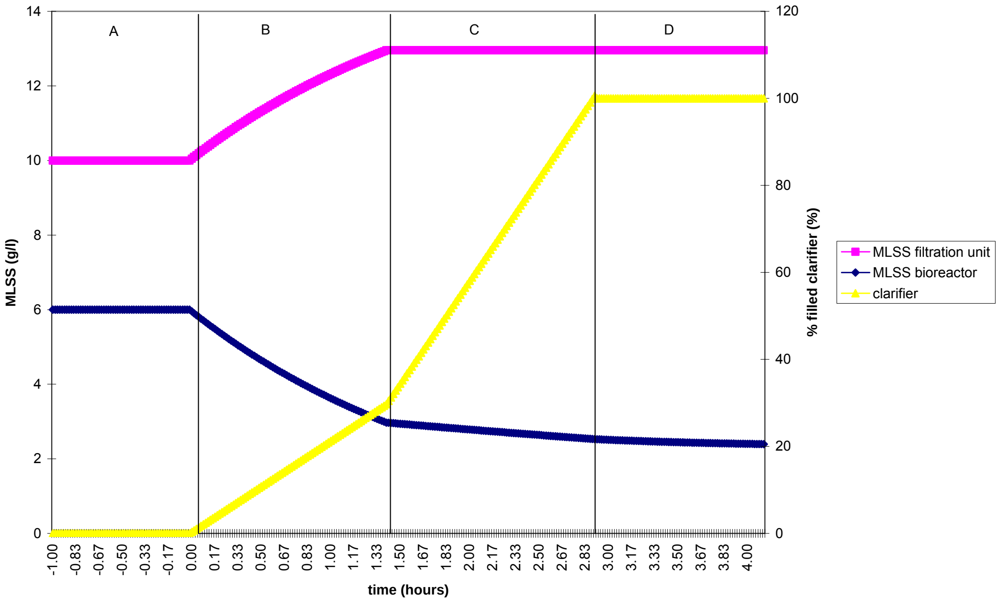
-MLSS concentration not constant → automisation flows necessary

Overview test periods Dual 2 CAS - MBR

- Period 1: only clarifier was working
- Period 2: CAS and MBR in parallel – constant influent condition
- Period 3: CAS and MBR in parallel – dynamic influent condition (dry/rain weather tests)
- The main parameters followed-up to determine feasibility:
  - Sludge Volume Index (SVI)
  - Concentration of suspended solids in effluent of clarifier

---

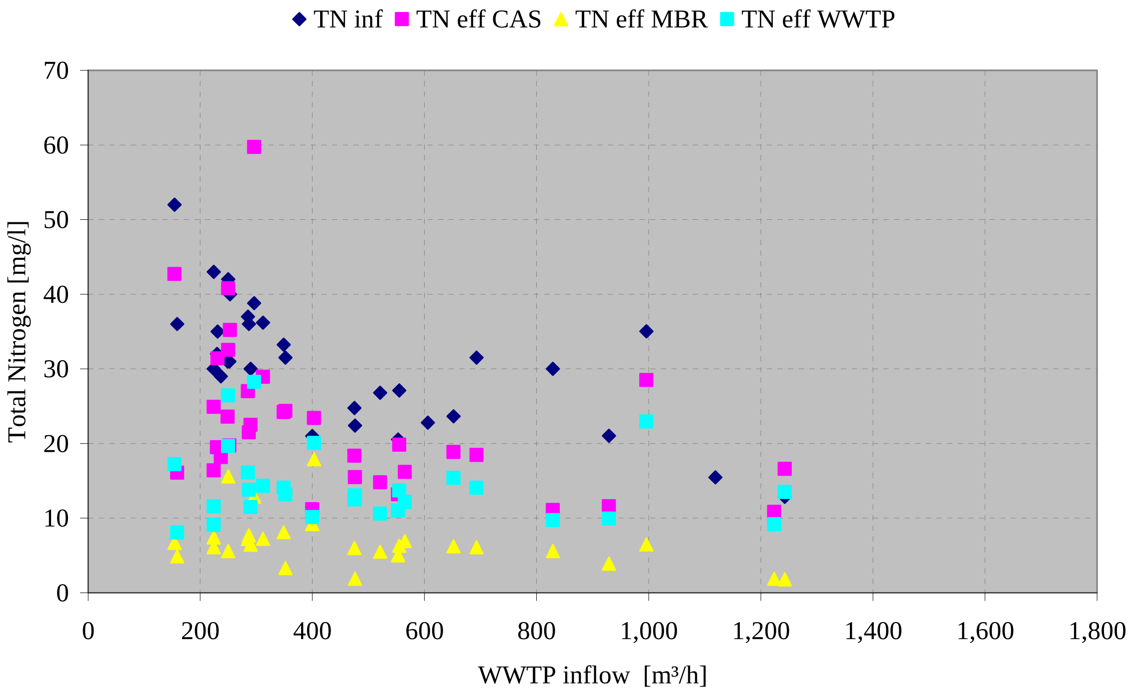
Period 3 – test scheme according patent application



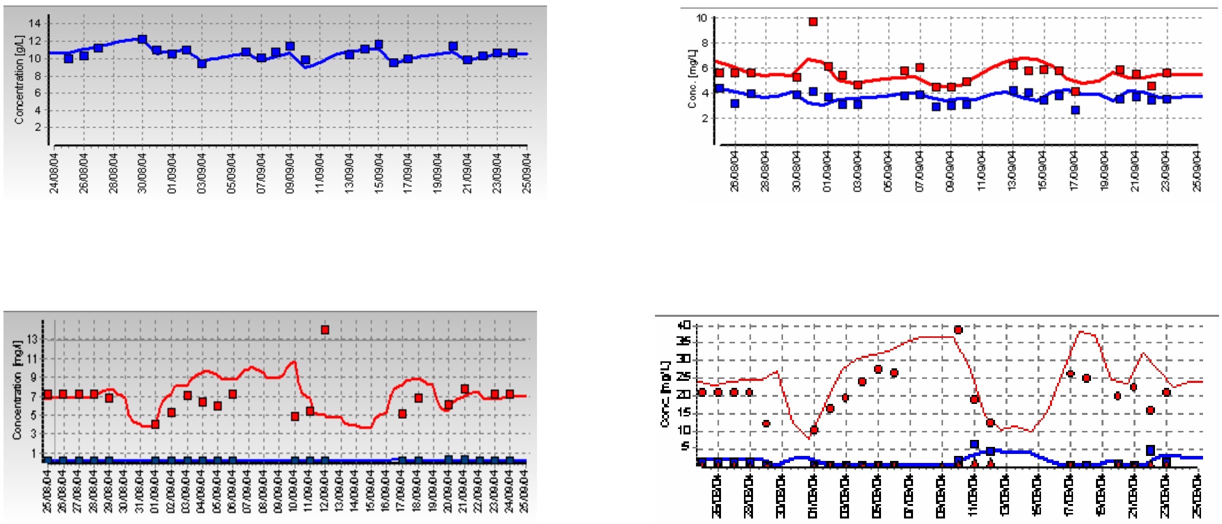
DW: $Q_{inf} = Q_{FT}$; $MLSS_{BIO}$=6 g/l; $MLSS_{FT}$ = 10 g/l

RW: $Q_{inf} = Q_{FT} + Q_{clarifier}$; $MLSS_{BIO}$= 2-3 g/l; $MLSS_{FT}$ = 13 g/l

Compliance with daily maximum for TN can be reduced by acting on the CAS lane



The CAS/MBR model is capable of describing the complex behaviour of the WWTP (2):



Strength of the Dual CAS-MBR concepts

- DUAL 1 + 2 :
- Membranes treat a fairly constant flow, the majority of the varying flow is handled in the CAS
- Membrane surface is reduced ➔ € !!
- Combined Effluent quality good, adapted to European consents
- Reuse possible

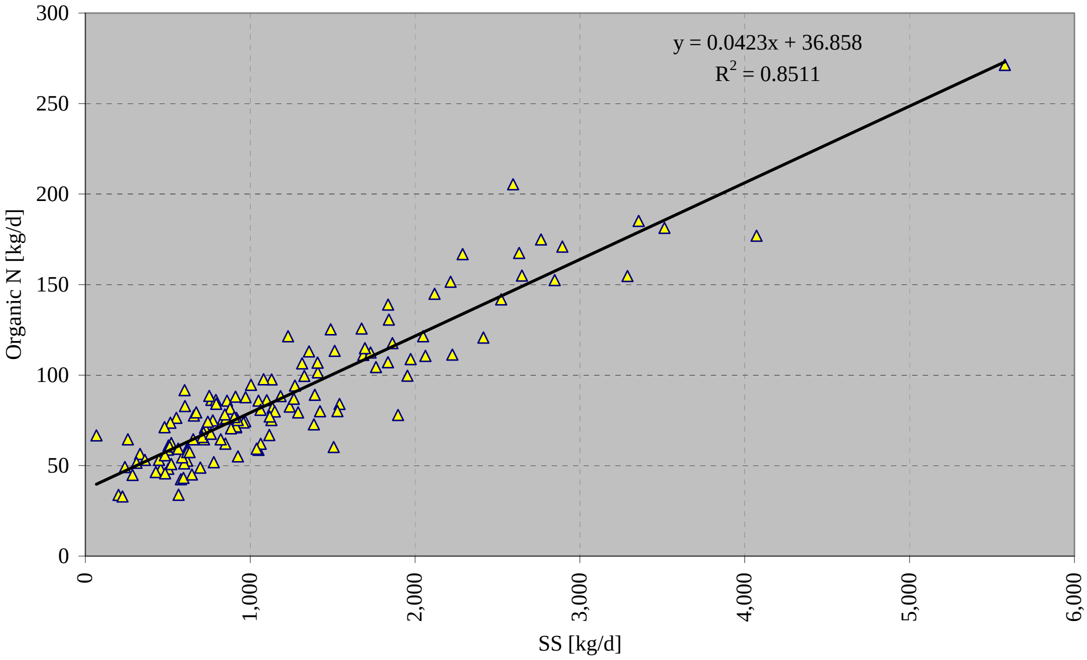
- DUAL 1 :
- Pollution load to the CAS is reduced (as part is taken over by the MBR)
- MBR is backed up by the conventional technology, minimizing investment risks and increasing operational stability

WP Structure

Task	**Description**	**Dual1/ Dual2**	**Scale**	**Location**
9.1	Optimised control strategy for influent split	Dual 1	Full-scale (230-355 m^3/h)	WWTP Schilde
9.2	Assess technological feasibility	Dual 2	Pilot-scale (1,5 m^3/h)	WWTP Schilde
9.3	Analysis of plant upgrade (technological and financial)	Dual1 +Dual2	Full-scale	EU new member states and candidate countries

Feedforward/feedback control (1)

$KJN_{INF} = f\,(Q_{WWTP},\ \text{pollutant sensor value})$



Period 3: overview tests

Test 02/04

Phase	Net permeate flow (l/h)	Sludge feed filtration tank (l/h)	Sludge feed flow clarifier (l/h)	Recirculation flow clarifier (l/h)
A	955	2000	0	0
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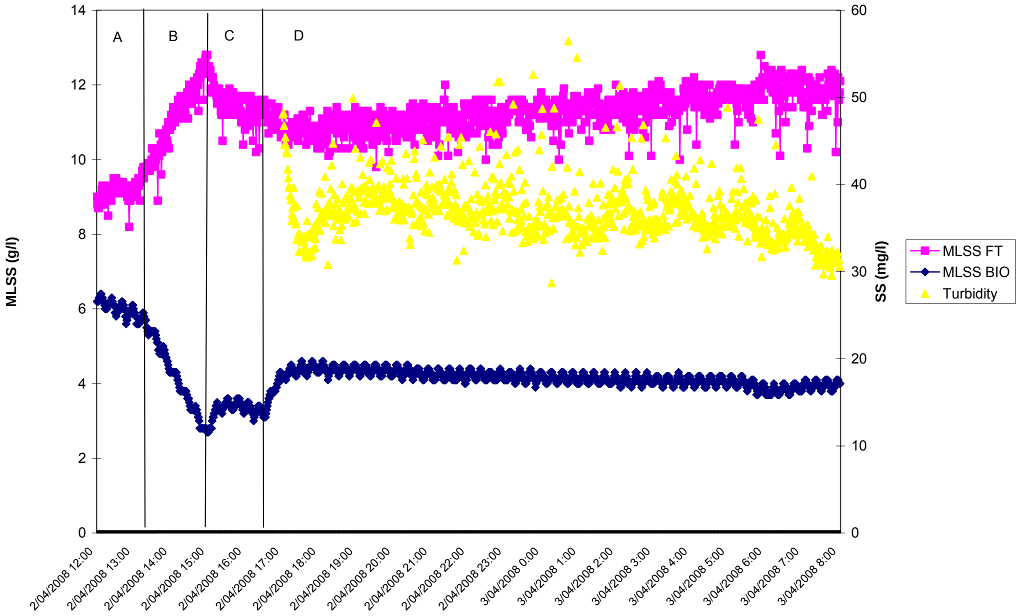
C	1200	± 1800	350	0
D	1200	1800	800	400

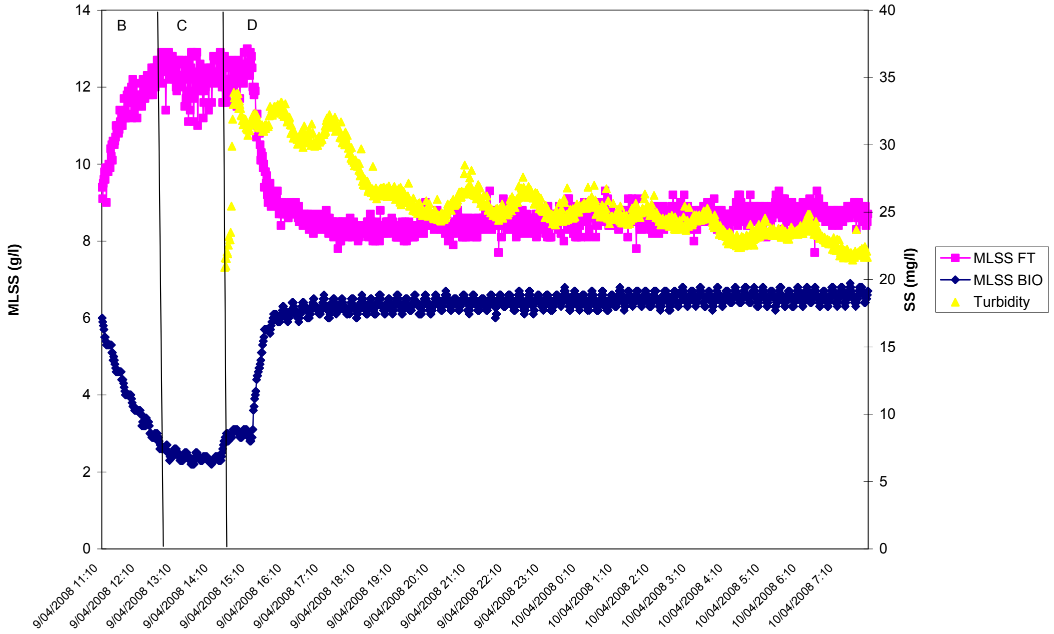
Period 3: overview tests

- Test 09/04

Phase	Net permeate flow (l/h)	Sludge feed filtration tank (l/h)	Sludge feed flow clarifier (l/h)	Recirculation flow clarifier (l/h)
A	955	2000	0	0
B	1445	± 1450	155	0
C	120			
D	1200	1800	800	400

-sludge blanket filtration




14
12
10
8
6
4
2
0
MLSS (g/l)
40
35
30
25
20
15
10
5
0
SS (mg/l)
B
C
D
MLSS FT
MLSS BIO
Turbidity
9/04/2008 11:10
9/04/2008 12:10
9/04/2008 13:10
9/04/2008 14:10
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10/04/2008 1:10
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10/04/2008 3:10
10/04/2008 4:10
10/04/2008 5:10
10/04/2008 6:10
10/04/2008 7:10

21. ADVANCED CONTROL OF MBR SYSTEMS USING ON-LINE FOULING SENSOR MEASUREMENTS

E. Brauns, E. Van Hoof, C. Huyskens, H. Elslander, F. Vanhoof, P. Lens, H. De Wever

AMEDEUS

Advanced control of MBR systems using on-line fouling sensor measurements

E. Brauns, E. Van Hoof, C. Huyskens, H. Elslander,
F. Vanhoof, P. Lens, H. De Wever
Flemish Institute for Technological Research (VITO), Belgium

vito vision on technology

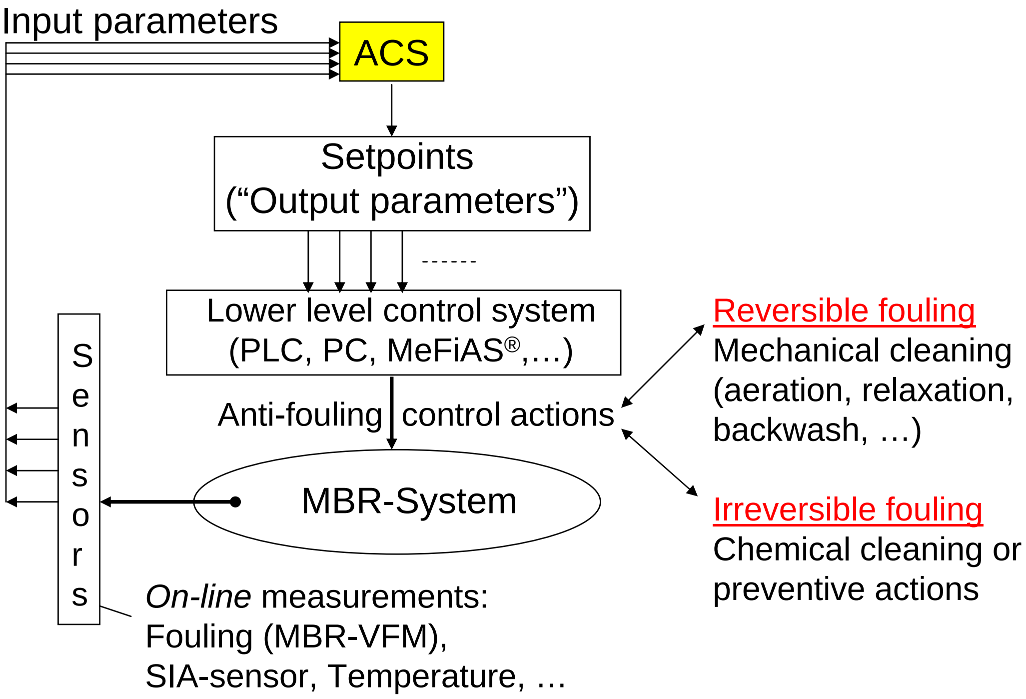
Aquafin

AMEDEUS

Rationale

- Basic control for MBR filtration system
  - Operating conditions often fixed at start-up with minor adaptations
    - Potentially suboptimal: e.g. too much aeration
    - Visual control evolution process parameters and manual adjustment
- Advanced control system (ACS) for filtration system
  - Higher level control supervising basic control system
  - Generate operational setpoints from actual fouling propensity
- Aim of ACS development and testing:
  obtain more optimal operation of filtration system through flexible and dynamic adjustment of operational setpoints

Approach Advanced Control System (ACS)



Input parameters

ACS

Setpoints
("Output parameters")

Lower level control system
(PLC, PC, MeFiAS®,…)

Anti-fouling control actions

MBR-System

Sensors

On-line measurements:
Fouling (MBR-VFM),
SIA-sensor, Temperature, …

Reversible fouling
Mechanical cleaning
(aeration, relaxation,
backwash, …)

Irreversible fouling
Chemical cleaning or
preventive actions

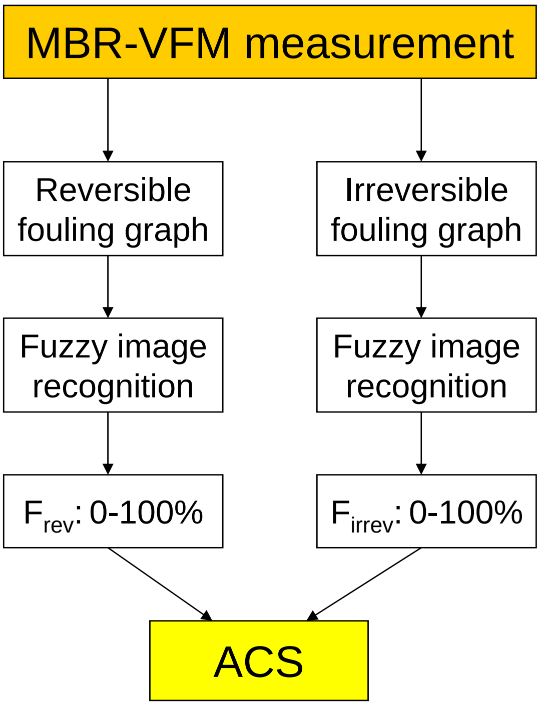
Matrix relating 14 input - 17 output parameters

		Primary input MBR-VFM	Additional input parameters			
#			pH	MLSS	Sludge age	…
1-3	Backwash					…
4-6	Backpulse					…
7-9	Aeration					…
10-11	Relaxation					…
12…	…					…
		ranges	7-8	10-15 g/l	10-30 d	

- Each output variable linked to relevant input parameters
- Distinction reversible – irreversible fouling
- Relation defined by Fuzzy Set Logic control blocks, capturing knowledge of human operators

Major input: VITO Fouling Measurement (VFM)

Mini submerged MBR:
accelerated (ir)reversible
fouling through specific
protocol filtration-relax-backwash



MBR-VFM measurement

Reversible fouling graph

Irreversible fouling graph

Fuzzy image recognition

Fuzzy image recognition

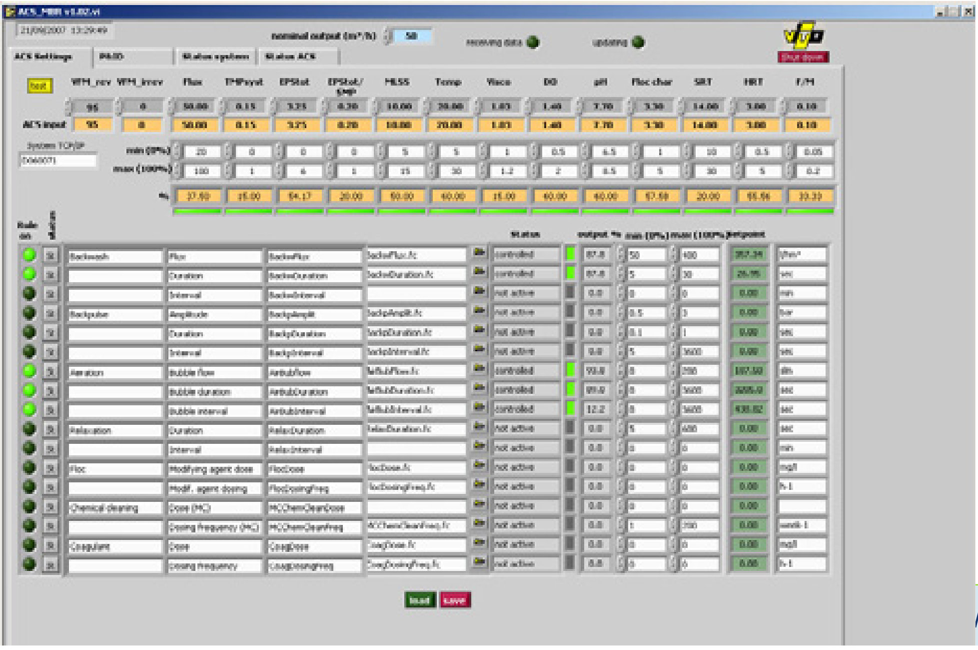
F_{rev}: 0-100%

F_{irrev}: 0-100%

ACS

ACS implementation in Labview

- Normalisation input and output parameters from 0-100%
    - universally applicable system (“implementation friendly”)
    - tuning of ACS is more transparent

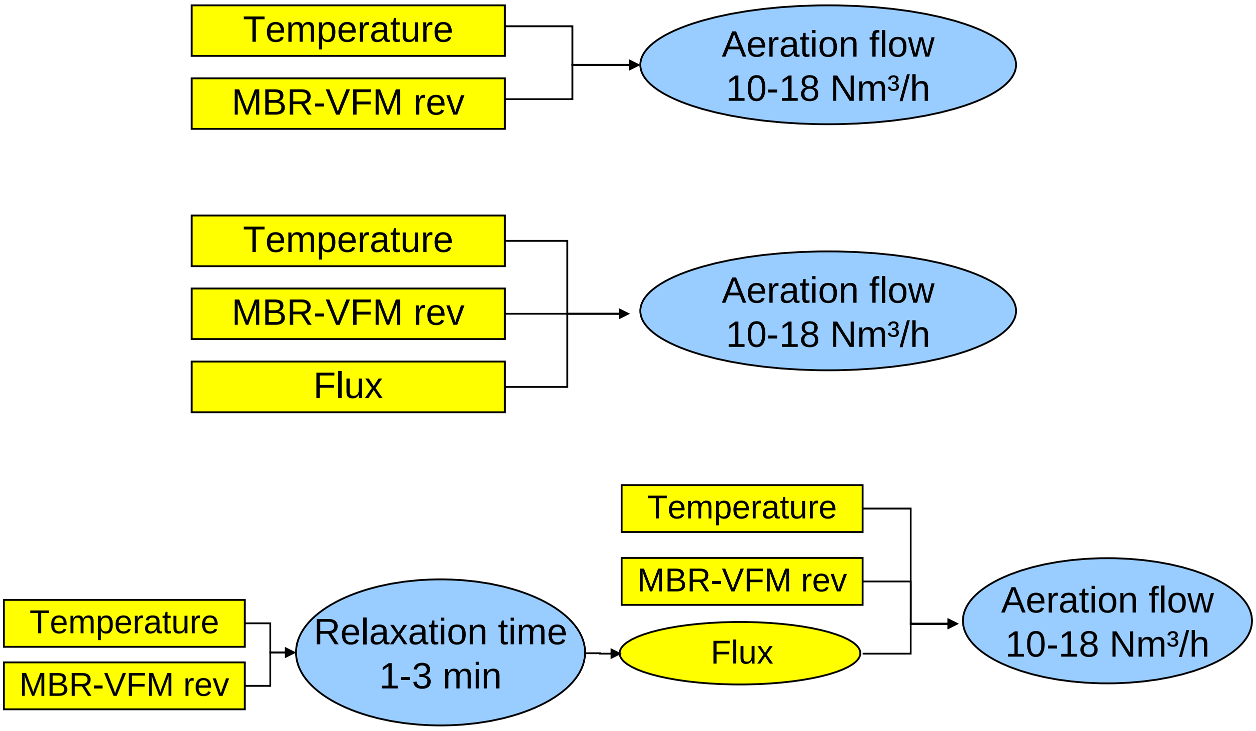


Validation of ACS through pilot testing

- Pilot MBR with A3 doubledeck module (40 m²)
- Test periods
  - Alternating without and with ACS control at increasing complexity
  - Final test under dynamic conditions
- Focus on filtration optimization and reversible fouling actions
  - Aeration
  - Relaxation


At WWTP Mol, Aquafin

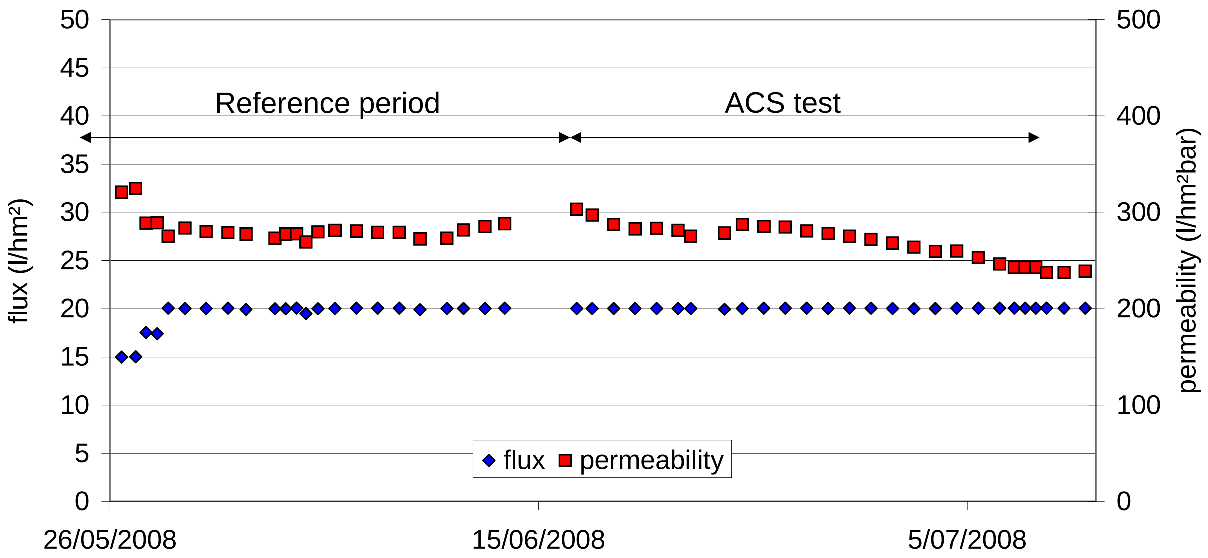
Pilot tests with and without ACS


Temperature
MBR-VFM rev
Aeration flow
10-18 Nm³/h

Temperature
MBR-VFM rev
Flux
Aeration flow
10-18 Nm³/h

Temperature
MBR-VFM rev
Relaxation time
1-3 min
Temperature
MBR-VFM rev
Flux
Aeration flow
10-18 Nm³/h

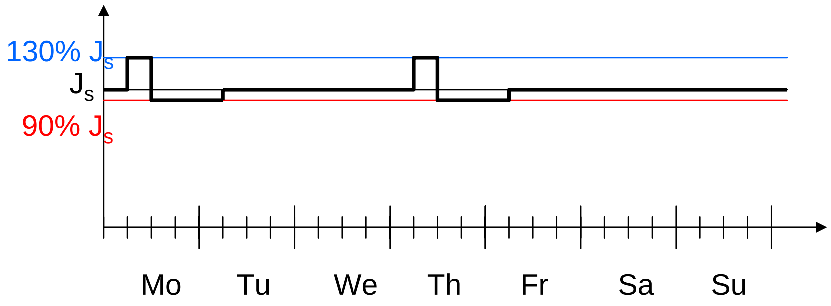
Pilot tests with and without ACS



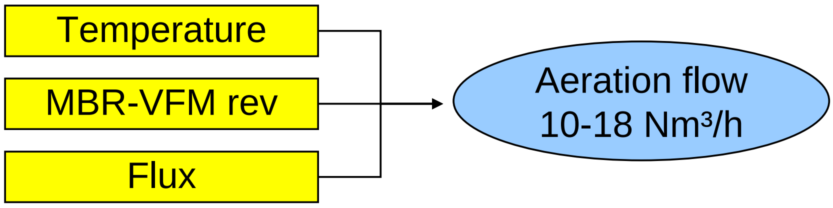
	REF	ACS
Aeration flow during filtration	18	11
Aeration flow during relaxation	18	10

ACS test under dynamic conditions

- Flux pattern:



- Input - output

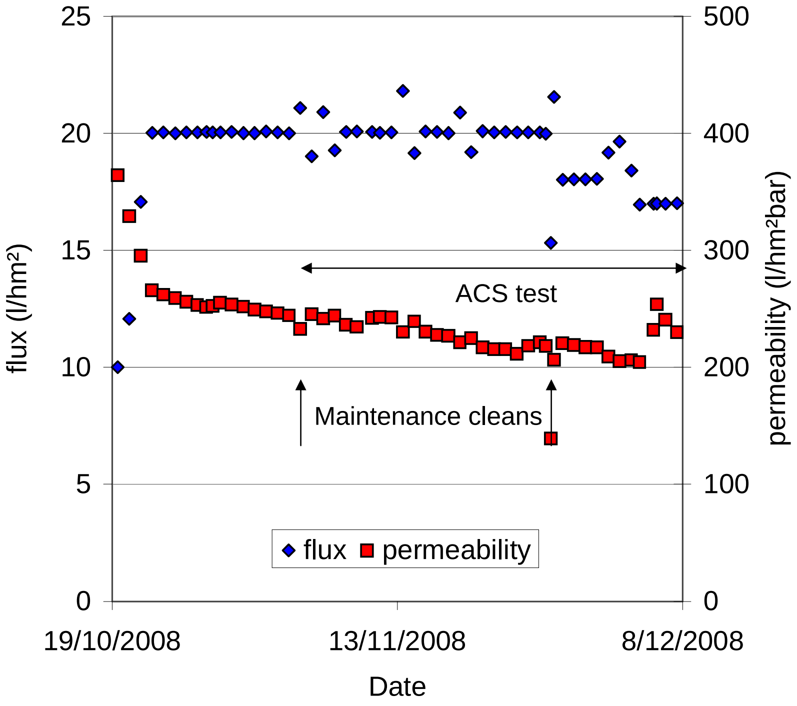

Temperature

MBR-VFM rev

Flux

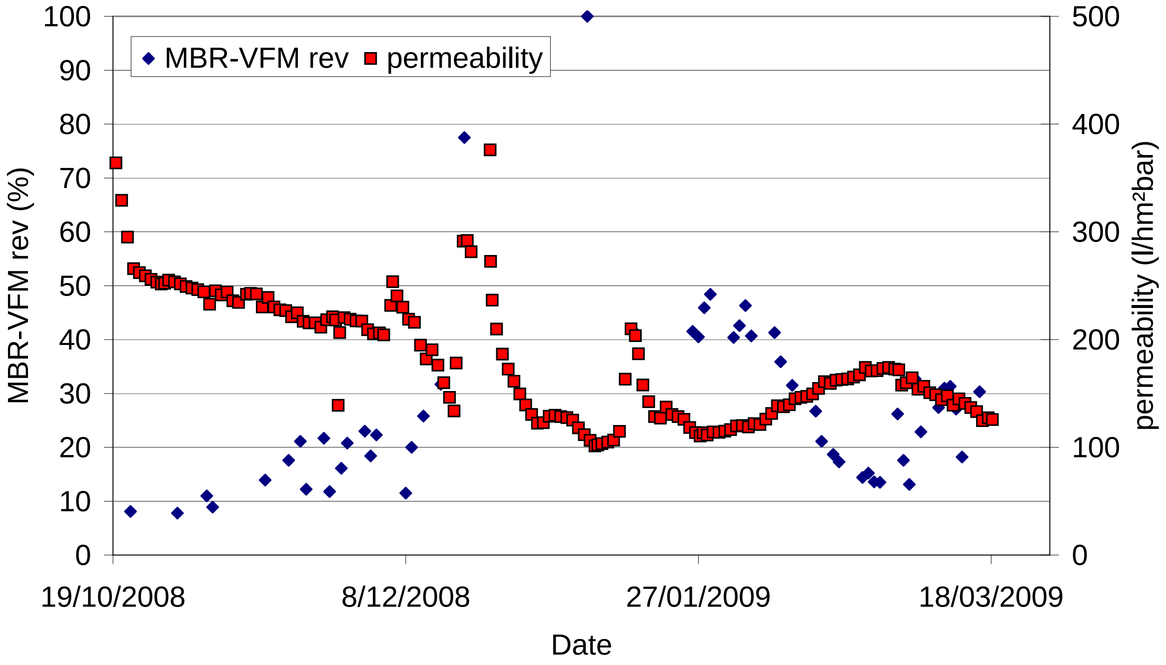
Aeration flow
10-18 Nm³/h

Evolution in membrane permeability



- Result:
  - 20% reduction in aeration during filtration
  - 25% reduction in aeration during relaxation
  - Similar permeability decline without and with ACS

Relation permeability - MBR-VFM measurements



Conclusions

- MBR-VFM measurements correlate with on-line permeability
  → *suitable tool as input for ACS*
- ACS operational - understandable interface - clear logging of changes operational conditions
  → *evaluated positively by MBR operators*
- Substantial reduction in aeration requirements, but sometimes at stronger decrease permeability (and higher cleaning frequency)
  → *detailed evaluation pending*
- First demonstration on pilot MBR with gradual increase in complexity but finetuning needed per application
- Future testing on chemical wastewater in Aquafit4use
  (www.aquafit4use.eu)

Acknowledgement

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by the European Commission
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Contract No. 018328 - AMEDEUS
Duration: 01/10/05 – 31/05/09
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More info: www.mbr-network.eu

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22. CFD ANALYSIS OF MBR-UNITS, RECOMMENDATIONS FOR SYSTEM DESIGN AND OPERATION

J. Saalbach, M. Hunze

CFD analysis of MBR-units
Recommendations for system design and operation

J. Saalbach & M. Hunze

Berlin, March 31th 2009

Overview

Topics:

- Project goal
- First step: Model development
- Second step: Case studies

  → Recommendations

Project goal

Development of universally valid recommendations for MBR-system design and operation with respect to

- the type and position of inlet and outlet
- the type of aeration, air-load, and mode of aeration
- module design
- the additional operation of mixers in MBR nitrification basins

by using CFD-modelling.

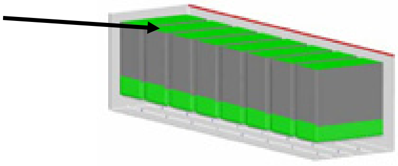
Step 1: Model development

- Fundamental question: Type of membrane modules approximation

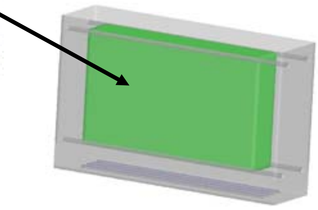
↓

- Assumption: Module can be modelled as porous zone

Puron Membran module;
www.kochmembrane.com



Toray Membrane module
www.toraywater.com



Hollow-fibre-membranes

Flat-sheet-membranes

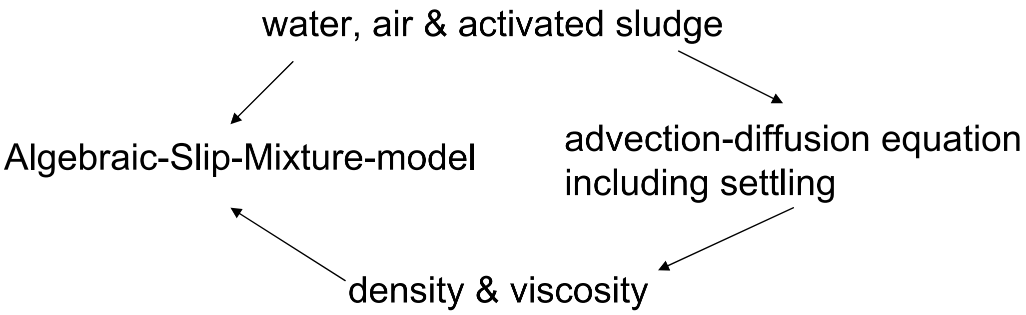
Step 1: Model development

Membrane modelling was calibrated by velocity measurements

↓

Result: Modules can be modelled as porous zones with appropriate flow resistance values

Numerical model



water, air & activated sludge

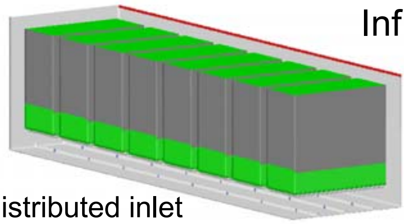
Algebraic-Slip-Mixture-model

advection-diffusion equation including settling

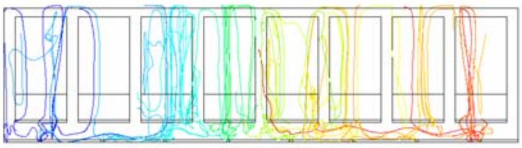
density & viscosity

Step 2: Case studies

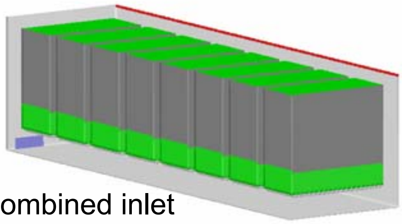
Influence of the inlet construction



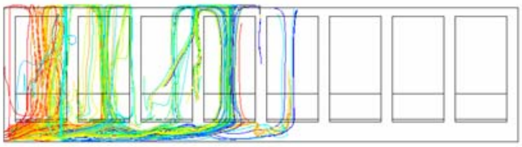
distributed inlet



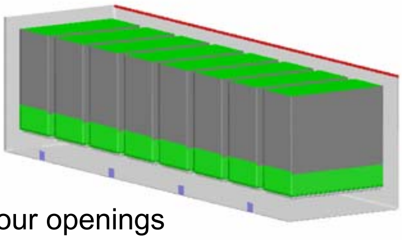
→ all modules get loaded



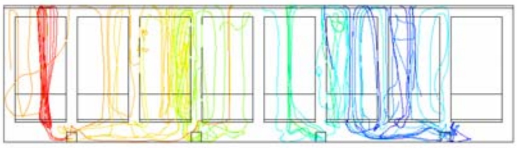
combined inlet



→ very uneven distribution throughout the modules



four openings



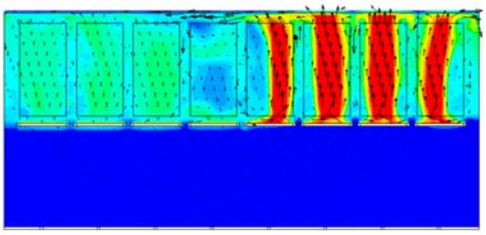
→ an almost even distributed loading of all modules

Conclusions Inlet Design

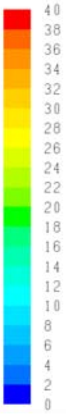
- filtration tank
  - mixing characteristics highly dependent on inlet design
  - distributed inlet advisable to load all modules equally

Step 2: Case studies

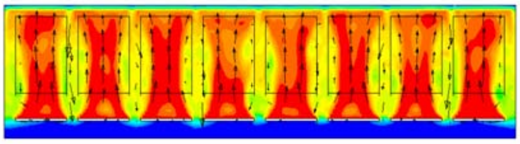
Influence of aeration mode



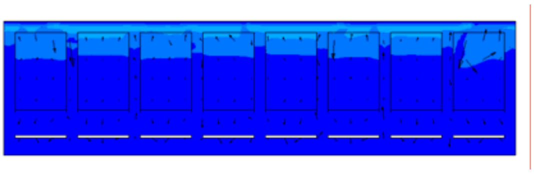
Air- cycle mode
→ only four modules in operation



[Vol %]



air distribution at the end of an aeration cycle and at the start of the next aeration cycle



→ after 99s off the system nearly comes to complete rest

Conclusions: Aeration mode

- flow field highly dependent on cross-flow aeration
- on- and-off-cycle influences the flow field
  (here: best mode with respect to membrane fouling
  has to be evaluated)

- aerated next to un-aerated module can be critical; this depends on the type of membranes

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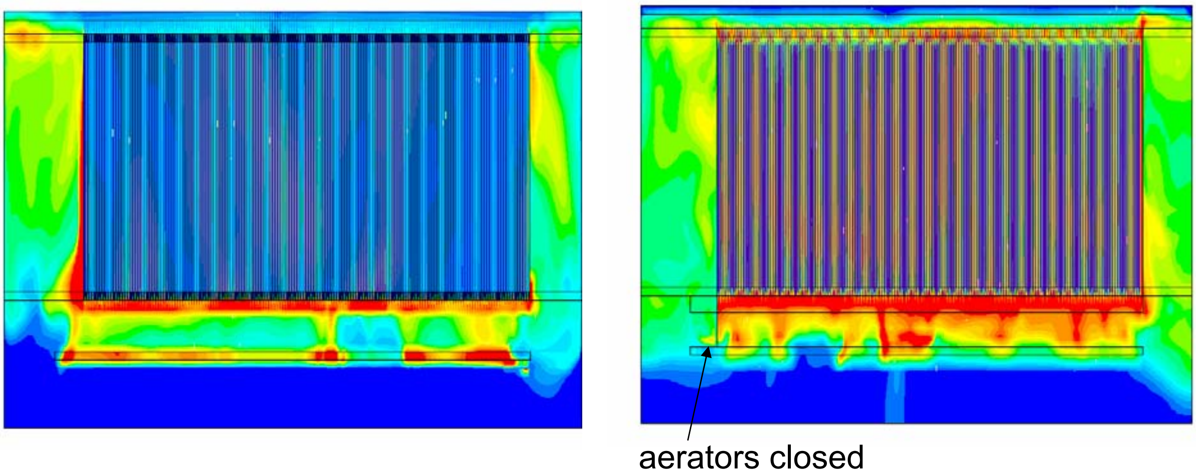
Step 2: Case studies

Influence of module design



aerators closed

air flows partly beside the module

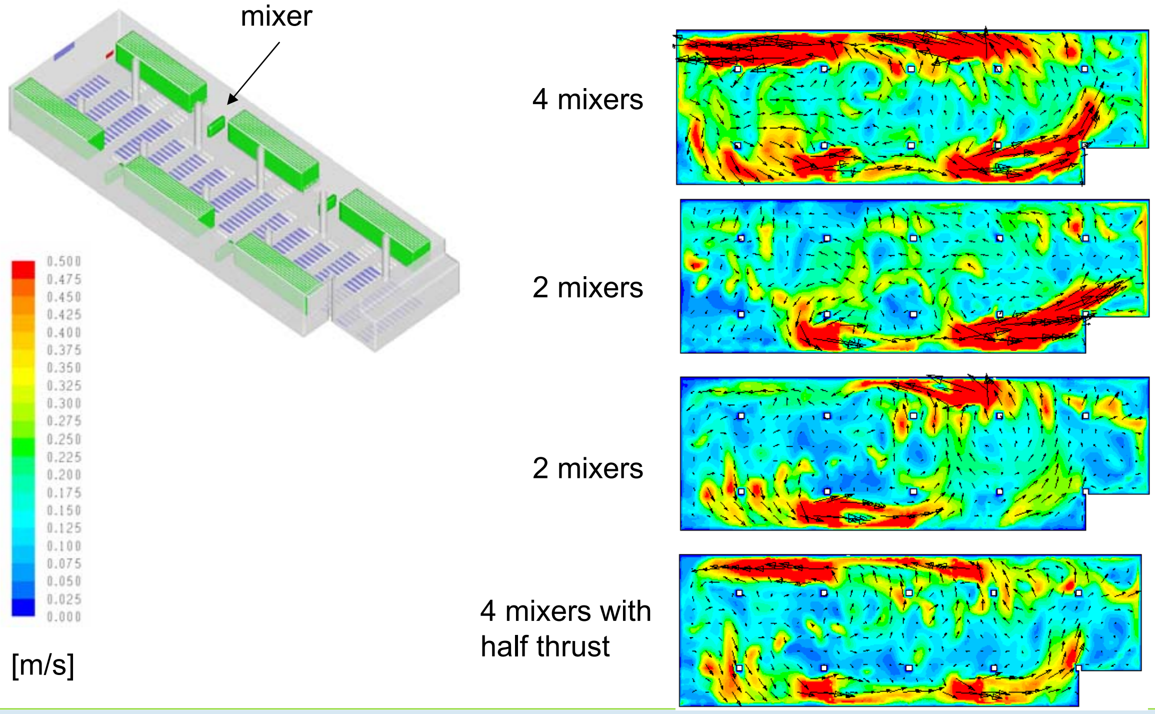
air only flows through the membranes

Conclusions: Module design

- closed modules support a better use of the aeration

Step 2: Case studies

Influence of additional mixers



4 mixers

2 mixers

2 mixers

4 mixers with half thrust

Conclusions: Additional Mixers

- the most import influence below the modules is given by the mixers
- the upper part of the system is mostly independent of mixers and is highly influenced by the cross-flow aeration

- all four mixers needed in order to prevent sedimentation (here: thrust can be reduced on a half)

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More info: www.mbr-network.eu

Thank you for your attention

FlowConcept GmbH
Vahrenwalder Straße 7
30165 Hannover
Germany

23. EVALUATION OF MIXING EFFICIENCY & NUTRIENT REMOVAL IN MEMBRANE BIOREACTORS VIA CFD MODELLING WITH EXPERIMENTAL VALIDATION

Y. Wang, M. Brannock, G. Leslie

AMEDEUS

Mixing profiles in flat sheet and hollow fibre MBRs

An important step in the development of a complete hydraulic model

Greg Leslie, Matthew Brannock, Yuan Wang
(Pierre Le-Clech)

Centre for Membrane Science and Technology
UNSW THE UNIVERSITY OF NEW SOUTH WALES

AMEDEUS

Complete hydraulic model?

- Current MBR design tools, such as BioWin® or WEST®, assume either complete mixing for aeration tanks or plug flow for anoxic channels
- Literature is silent about effect of MBR hydrodynamics on modeling
    - Ng and Kim, *A mini-review of modeling studies on membrane bioreactor (MBR) treatment for municipal wastewaters*, Desalination 212 (2007) 261-281
- Why hydrodynamics may be important in MBR design?
    - Mixing can affect the efficiency of organic removal, the settling of the sludge and fouling propensity.
    - MBR cost for energy contributes to approximately 50% of the total operating costs; over 90% of energy usage influences mixing, so room for optimisation

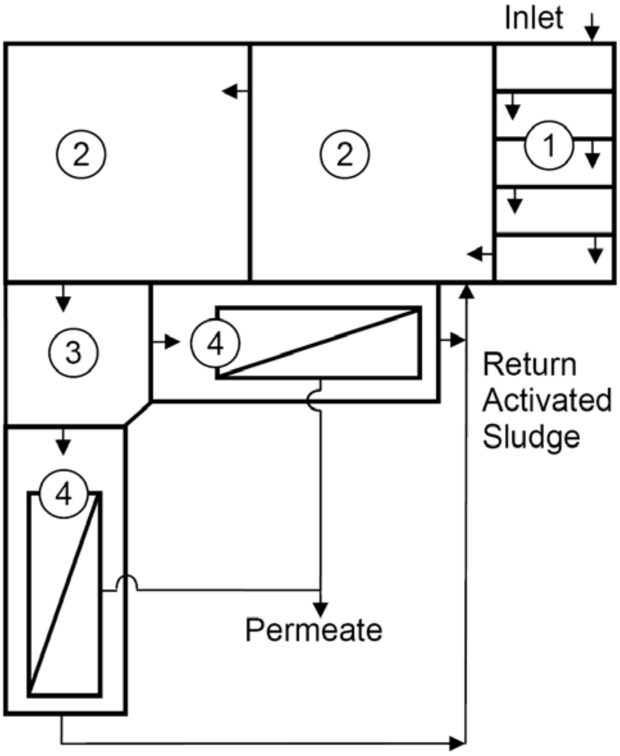
UNSW Contribution to AMEDEUS

- Development of computer model (which includes mixing considerations) for the design of full-scale MBRs
  - Based on residence time distribution (RTD) and
  - Computational fluid dynamics (CFD)
- Work package includes the examination of the hydrodynamic effect of:
  - Membrane module configuration (Hollow fibre vs. flat sheet)
  - Module location (Inside vs. outside submerged systems)
  - Primary sedimentation (raw vs. settled sewage)

Australian Full-Scale MBRs
- Site 1: Flat Sheet (FS) MBR

Flat Sheet (FS) MBR

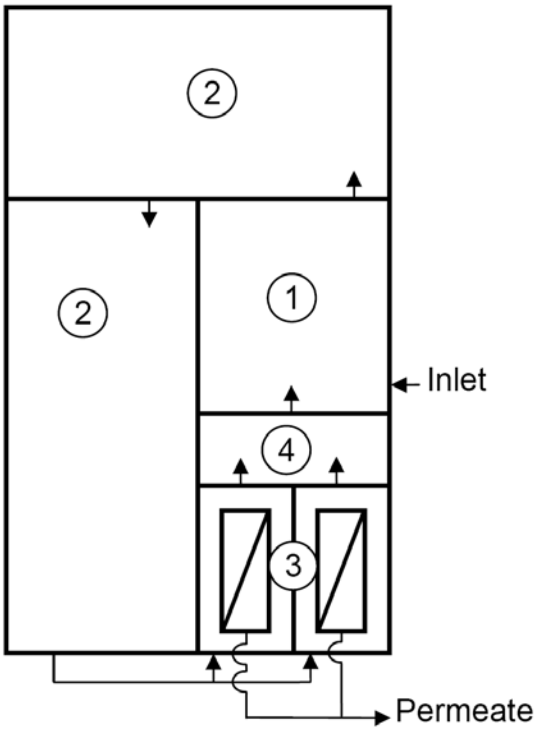
1. Bioselector (anoxic/anaerobic)
2. Swing aeration zones
3. Aerobic zone
4. Membrane filtration vessels



Site 2: Hollow Fiber (HF) MBR

Hollow Fibre (HF) MBR

1. Anoxic zone
2. Aerobic zones
3. Membrane filtration zone
4. De-aeration zone



MBR operating conditions

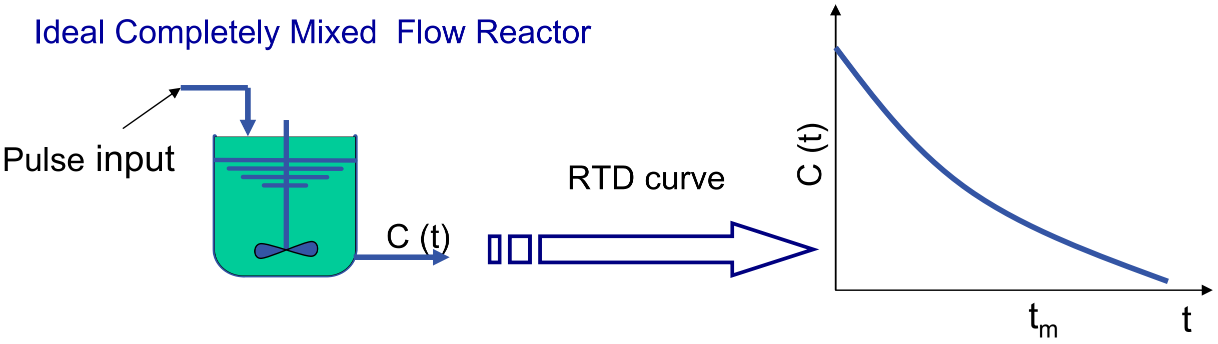
Parameters	**Units**	**FS MBR**	**HF MBR**
Average Permeate Flowrate	Ml/d	1.09	1.10
Volume of Bioreactor Vessels	m^3	852	435
Volume of Membrane Filtration Vessels	m^3	392	36
Membrane Area	m^2	3835	3200
MLSS	g/L	11.3	5.0
Mixed Liquor Return Flowrate	m^3/hr	461	433
Sludge Age	days	16.6	9.9
Net Membrane Flux	L/m^2/hr	11.8	14.3
Air Flowrate into Bioreactor	Nm^3/hr	109	419
Air Flowrate into Membrane Vessel	Nm^3/hr	992	918

Power Requirements

Parameters/Comparison Standards	Units	FS MBR	HF MBR
Power - Mixer	kW	7.1	2.2
Power - Bioreactor Blower	kW	3.3	8.5
Power - Membrane Vessel Blower	kW	29.5	13.8
Power - Recirculation Pump	kW	16.0	18.5
Power - Total	kW	55.8	42.9
Total Power Input / Reactor volume	*W/m^3*	***44.8***	***91.2***
Total Power Input / MLSS	*W/(mg/L)*	***4.94***	***8.58***
Total Power Input / Permeate	*kWh/m^3*	***1.23***	***0.939***
Total Power Input / COD removed	*W/(mg/L)*	***99.79***	***94.70***
Memb. Blower Power Input / Membrane Area	*W/m^2*	***7.69***	***5.78***
Memb. Blower Power Input / Permeate	*kWh/m^3*	***0.651***	***0.301***

How to measure residence time distribution?

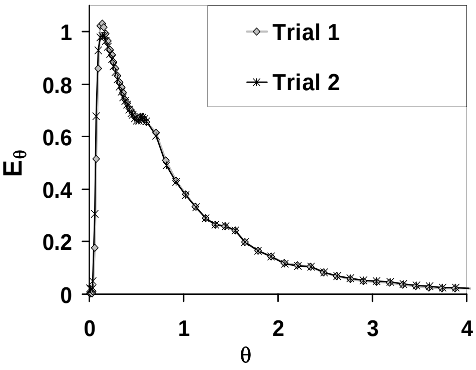
- Introduction of inert tracer in the inlet of system and monitoring its concentration in the outlet, to obtain C(t)



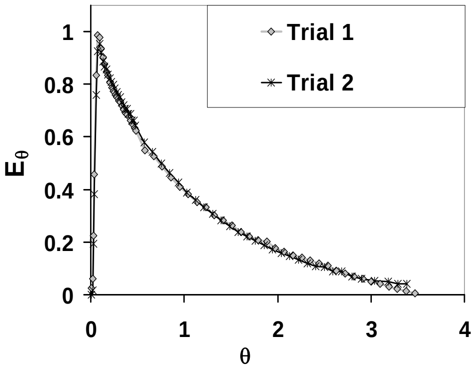
- Tracer study can provide
  - Diagnosis mixing problem: Short-circuiting, dead/stagnant zones
  - Effective reactor volume vs. theoretical reactor volume
  - Actual mean residence time vs. hydraulic residence time
  - Degree of dispersion: Peclet number

Residence Time Distribution

Flat Sheet MBR



Hollow Fiber MBR



Quantitative RTD properties	FS MBR	HF MBR
Tracer Recovery	99.5%	96.0%
Peclet Number, Pe_r	0.34	0.66
Number of Tanks in Series, *N*	1.11	1.24

Experimental methodology with high reproducibility & tracer recovery, allowing accurate problem diagnosis

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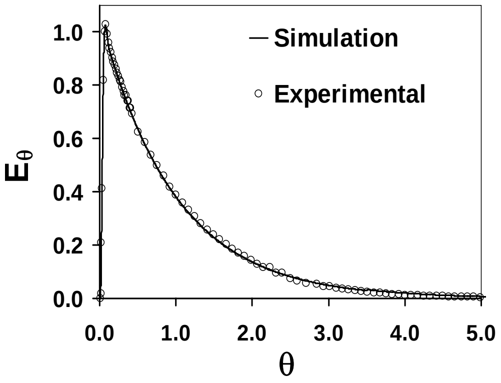
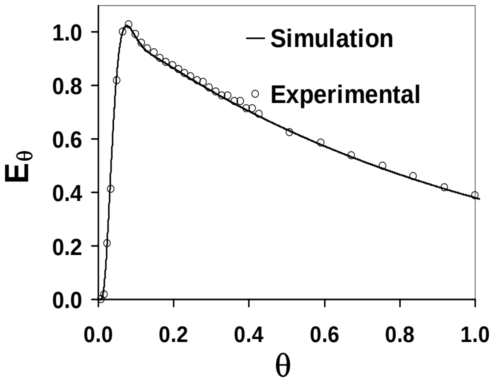
CFD Model Validation – HF MBR

θ = 0 to 5.0



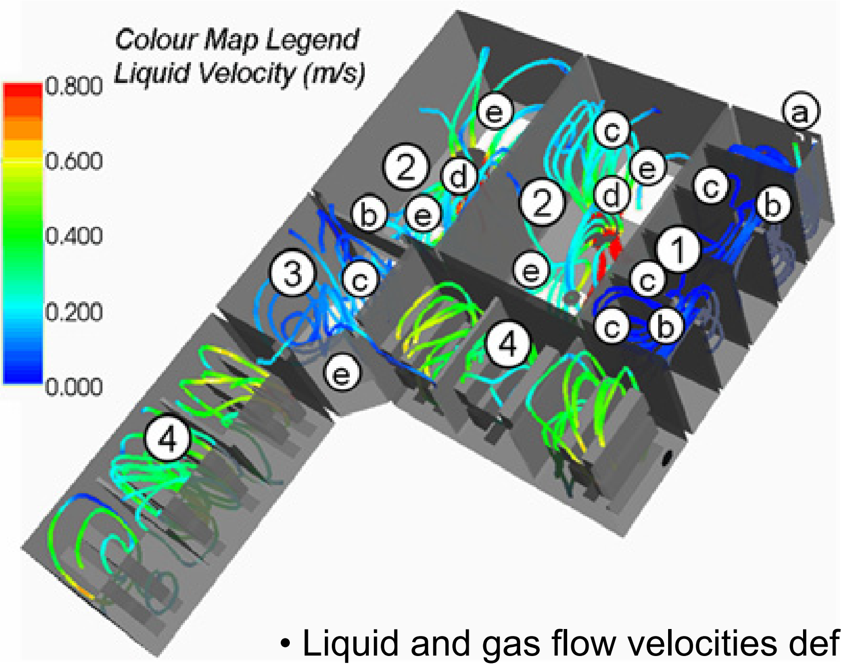
θ = 0 to 1.0



- CFD model, validated by experimental data and which can successfully reproduce the RTD of full-scale MBR plants

- Energy optimisation is feasible (and still resulting in good mixing)
- Effect of aeration on fouling will become the limiting factor

Qualitative CFD Results – FS MBR



Process units:

1) **Bioselector**
2) **Swing aeration zones**
3) **Aerobic zone**
4) **Membrane zones**

Design aspects:

a) **Main inlets**
b) **Overflow weir**
c) **Underflow**
d) **Mixer**
e) **Aerator**

- Liquid and gas flow velocities defined
- Identification of low mixing zones

Other research activities

- Raw vs. settled sewage systems
  - RTD conducted with pilot plants installed at Anjou Recherche
  - Minimum effect of rheology on simulated RTD
  - The developed CFD model shows significantly superior performance in terms of predicting mixing than the widely used compartmental models
- Inside vs. outside systems
  - Computational fluid dynamics simulations of MBRs: Inside submerged versus outside submerged membranes. Desalination 236 (2009) 244-251.
- Inclusion of bioreactions into CFD model
  - See poster

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