Modelling SMPs in MBRs

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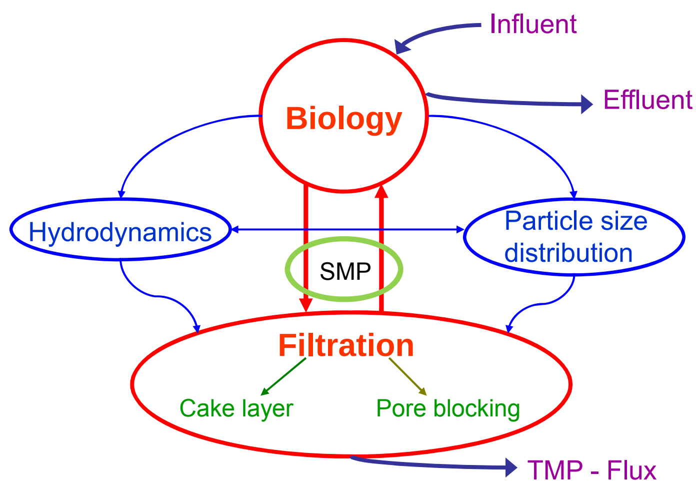
1st IWA/WEF Wastewater Treatment Modelling Seminar
Mont-Sainte-Anne QC, Canada, June 1-3, 2008

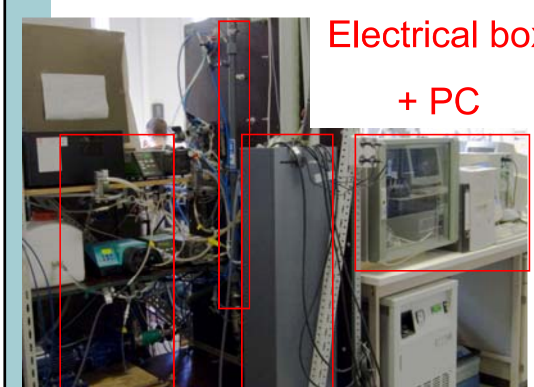
Outline

- ASM2d model application to MBR:
  - Parameters
  - Performance
- Soluble Microbial Products
  - UAP & BAP experiments
  - Characterization by LC-OCD
- ASM2dSMP model development
- SMP and fouling

MBR Research @ BIOMATH



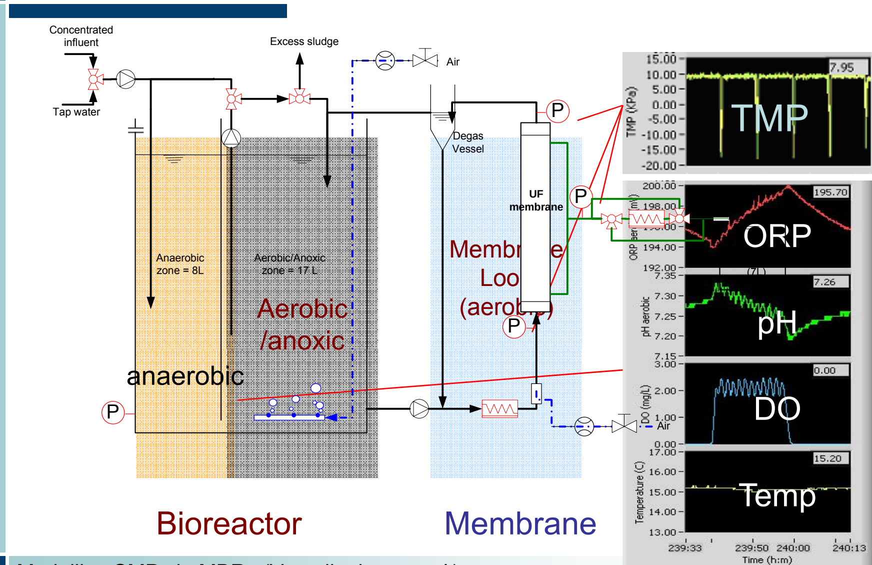
Lab-scale sidestream MBR



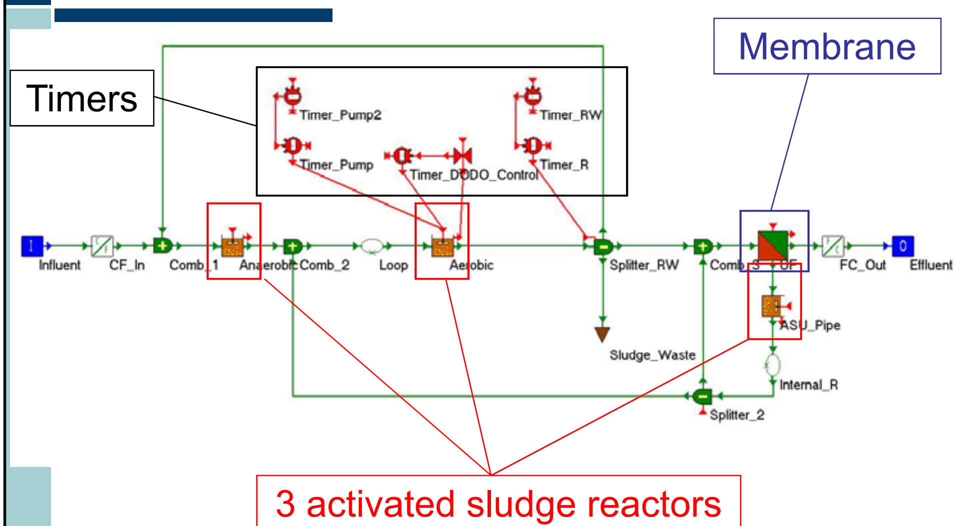
- Biol. COD, N & P removal
- SRT = 17 d
- HRT = 6.4 hr
- Temperature = 15 °C
- Fully automated
- Cyclical aeration & recirculation for N/P rem.

Modelling SMPs in MBRs (Vanrolleghem *et al.*)

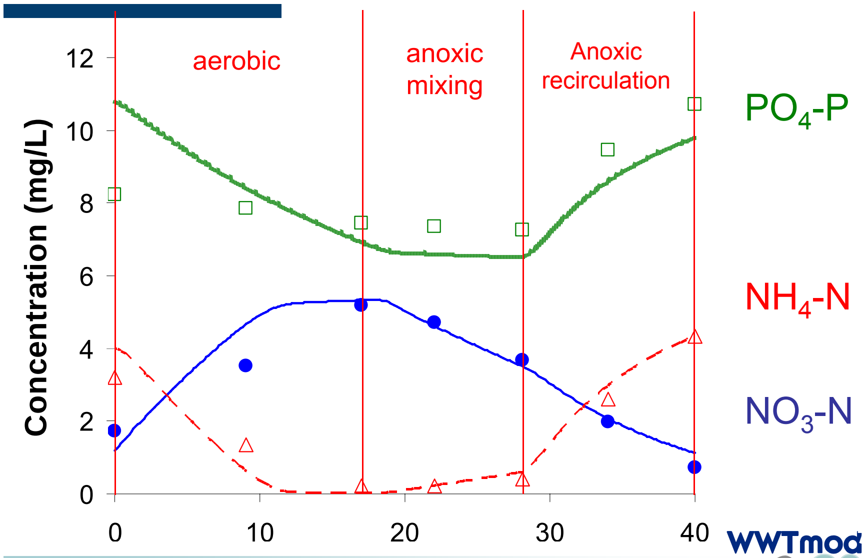
Lab-scale sidestream MBR



ASM2d Model in WEST®



ASM2d Calibration: N & P results



ASM2d calibration: Parameters

Slower

Parameter name	Symbol	Unit	Default	Calibrated
Decay rate of nitrifiers	b_{aut}	1/d	0.15	0.055
Maximum growth rate of nitrifiers	μ_{aut}	1/d	1	0.6
Oxygen half-saturation coefficient of nitrifiers	$K_{O,aut}$	mg O_2/L	0.5	0.2
Ammonium half-saturation coefficient of nitrifiers	$K_{NH4,aut}$	mg N/L	1	0.2
Reduction factor of anoxic growth of heterotrophs				
Fermentation rate of acetate production	q_{fe}	1/d	3	1
PHA storage rate	q_{PHA}	1/d	3	5
Phosphate uptake rate	q_{pp}	1/d	1.5	1.1
Reduction factor of anaerobic hydrolysis	$\eta_{NO3, PAO}$	-	0.6	0.4

Higher affinity ← smaller flocs

ASM2d calibration: COD results

Sample	Item (Unit)	Measured	Simulation (ASM2d)
Waste sludge	Total COD (g COD/L)	10.9	10.83
Sludge water (reactor)	SCOD (mg COD/L)	87.4	4.5
Sludge water (mem. loop)	SCOD (mg COD/L)	107.4	5
Effluent	COD (mg COD/L)	11	5
	NH_4^+-N (mg N/L)		
	NO_3^--N (mg N/L)	7.03	8.6
	PO_4^{3-}-P (mg P/L)	5.63	5.3

ASM2d ☹

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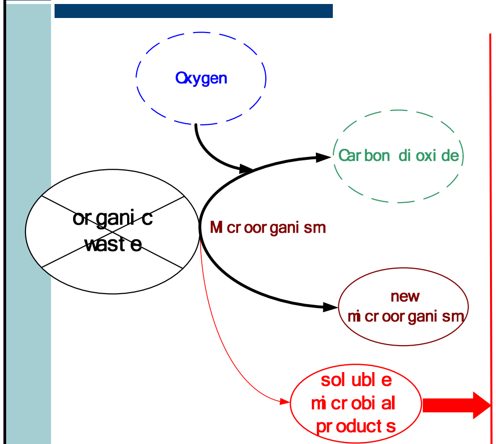
Soluble Microbial Products (SMP)



- SMP < 0.45 µm
- SMP → fouling
- SMP
  = protein + polysaccharide
  …
- SMP
  = BAP (decay products)
  + UAP (growth by-products)

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Modelling SMPs in MBRs (Vanrolleghem *et al.*)

SMP experiment: Overview

<u>SMP</u> (*BAP+UAP*)
- Directly from MBR (< 0.45 µm)

<u>BAP</u> (*Biomass Associated Products*)
- Produced in BAP batch (starvation, < 0.45 µm)

<u>UAP</u> (*Utilization Associated Products*)
- Produced in UAP batch (growth on S_S, <0.45µm)

Non-stirred cell filtration of SMP, BAP & UAP
- Same membrane characteristics as MBR one
- LC-OCD analysis of feed and permeate

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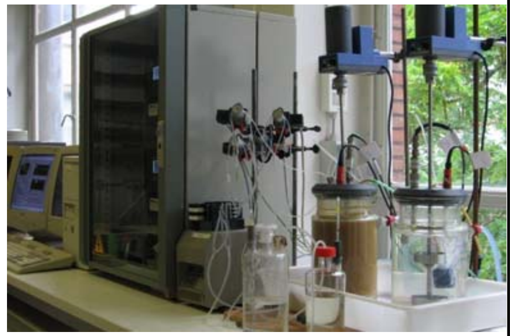
Modelling SMPs in MBRs (Vanrolleghem *et al.*)

Batches producing BAP & UAP

- Experimental conditions
  - 2 L reactor
  - Washed MBR sludge
  - 15 °C, pH=7.5±0.1,
  - Aerobic : Anoxic time = 7:10
  - DO = 1.5-2.5 mg/L (aerobic)

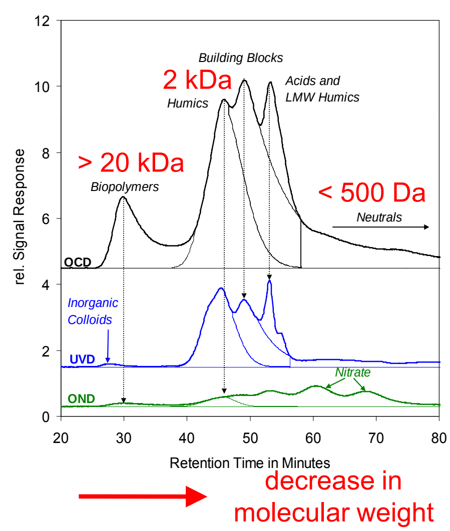


- BAP production
  - No substrate addition (decay process for 19 days)
- UAP production
  - Acetate addition (growth process for 24 hours)
  - No acetate addition (reference)

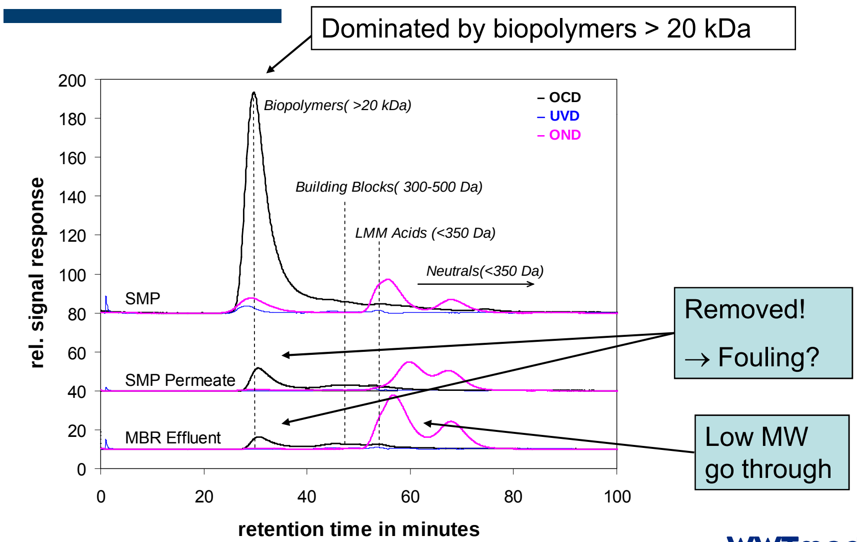
Understanding LC-OCD

Liquid chromatography
- SEC, size exclusion chromat.
  separation by size,
  size expressed in dalton (Da)

Organic carbon detection – OCD
Organic nitrogen detection – OND
UV detection 254 nm – UVD
SUVA $=UV_{254}/DOC$

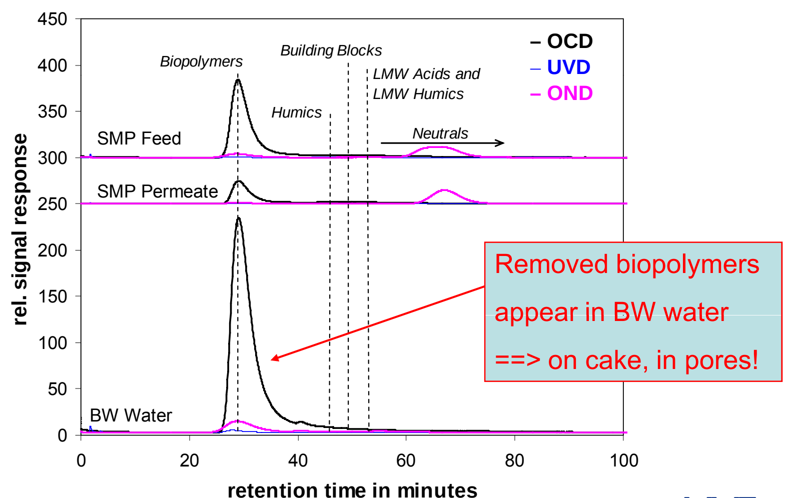


Batch filtration of SMP



Modelling SMPs in MBRs (Vanrolleghem *et al.*)

Membrane backwashing



Modelling SMPs in MBRs (Vanrolleghem *et al.*)

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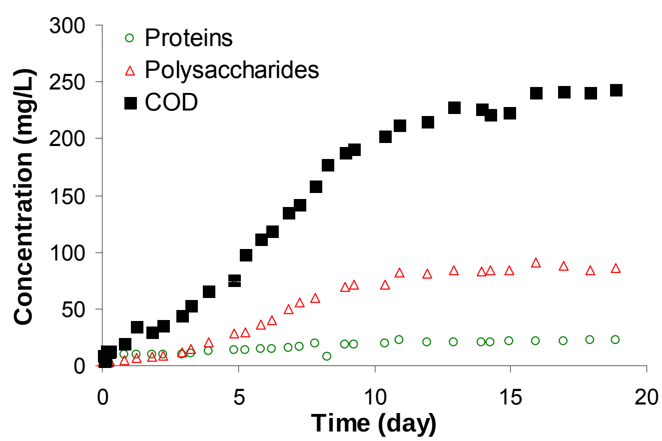
Modelling SMPs in MBRs (Vanrolleghem *et al.*)

BAP production (starvation)

Sludge water composition



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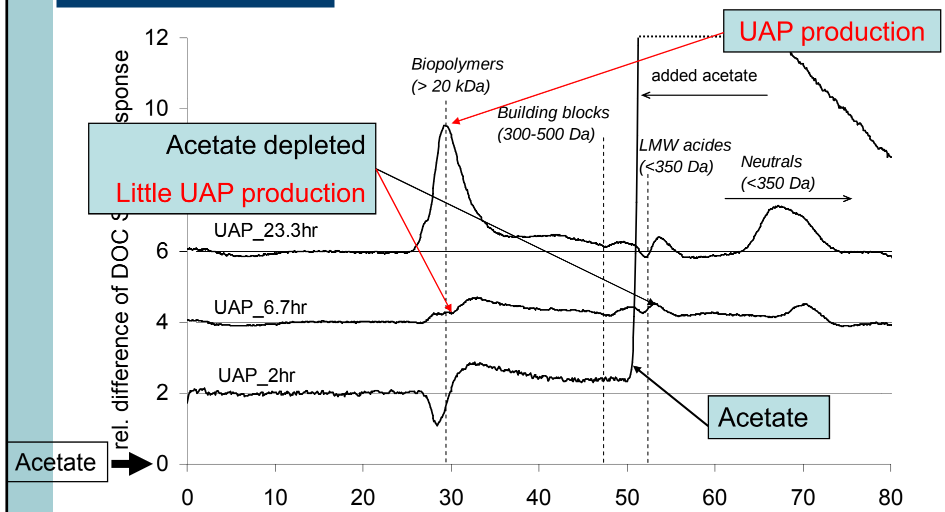
Modelling SMPs in MBRs (Vanrolleghem *et al.*)

Net UAP production ($UAP_{HAc} – UAP_{ref}$)



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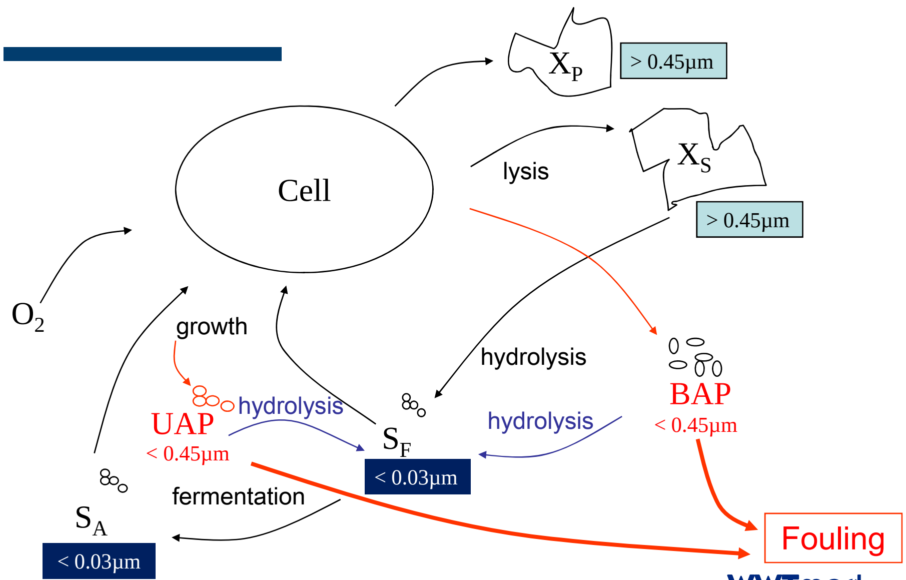
ASM2dSMP introduction



Modelling SMPs in MBRs (Vanrolleghem *et al.*)

ASM2dSMP – Gujer matrix: BAP

Processes	S_F	S_{BAP}	S_I	X_I	X_S	X_H	X_{PAO}	X_{AUT}	rate
Aerobic Hydrolysis of BAP	$1-f_{SI}$	-1	f_{SI}						$k_{h,BAP}\frac{S_O}{K_O+S_O}S_{BAP}X_H$
Anoxic Hydrolysis of BAP	$1-f_{SI}$	-1	f_{SI}						$k_{h,BAP}\eta_{NO3}\frac{K_O}{K_O+S_O}\frac{S_{NO3}}{K_{NO3}+S_{NO3}}S_{BAP}X_H$
Anaerobic Hydrolysis of BAP	$1-f_{SI}$	-1	f_{SI}						$k_{h,BAP}\eta_{fe}\frac{K_O}{K_O+S_O}\frac{K_{NO3}}{K_{NO3}+S_{NO3}}S_{BAP}X_H$
Lysis of X_H		f_{BAP}		f_{XI}	$1-f_{XI}-f_{BAP}$	-1			$b_H X_H$
Lysis of X_{PAO}		f_{BAP}		f_{XI}	$1-f_{XI}-f_{BAP}$		-1		$b_{PAO}X_{PAO}\frac{S_{ALK}}{K_{ALK}+S_{ALK}}$
Lysis of X_{AUT}		f_{BAP}		f_{XI}	$1-f_{XI}-f_{BAP}$			-1	$b_{AUT}X_{AUT}$

Modelling SMPs in MBRs (Vanrolleghem *et al.*)

ASM2dSMP – Gujer matrix: UAP

Processes	S_O	S_F	S_A	S_{UAP}	S_{NO}	S_I	X_H	X_{PAO}	X_{AUT}	rate
Aerobic Hydrolysis of UAP		$1-f_{SI}$		-1		f_{SI}				$k_{h,UAP}\frac{S_O}{K_O+S_O}S_{UAP}X_H$
Anoxic Hydrolysis of UAP		$1-f_{SI}$		-1		f_{SI}				$k_{h,UAP}\eta_{NNO3}\frac{K_O}{K_O+S_O}\frac{S_{NO3}}{K_{NO3}+S_{NO3}}S_{UAP}X_H$
Anaerobic Hydrolysis of UAP		$1-f_{SI}$		-1		f_{SI}				$k_{h,UAP}\eta_{fe}\frac{K_O}{K_O+S_O}\frac{K_{NO3}}{K_{NO3}+S_{NO3}}S_{UAP}X_H$
Aerobic growth of X_H on S_F	$-\frac{1-Y_H-f_{UAP}}{Y_H}$	$-\frac{1}{Y_H}$		$\frac{f_{UAP}}{Y_H}$			1			$\mu_H\frac{S_O}{K_O+S_O}\frac{S_F}{K_F+S_F}\frac{S_F}{S_A+S_F}\frac{S_{NH}}{K_{NH}+S_{NH}}\frac{S_{PO}}{K_{PO}+S_{PO}}\frac{S_{ALK}}{K_{ALK}+S_{ALK}}X_H$
Aerobic growth of X_H on S_A	$-\frac{1-Y_H-f_{UAP}}{Y_H}$		$-\frac{1}{Y_H}$	$\frac{f_{UAP}}{Y_H}$			1			$\mu_H\frac{S_O}{K_O+S_O}\frac{S_A}{K_A+S_A}\frac{S_A}{S_F+S_A}\frac{S_{NH}}{K_{NH}+S_{NH}}\frac{S_{PO}}{K_{PO}+S_{PO}}\frac{S_{ALK}}{K_{ALK}+S_{ALK}}X_H$
Anoxic growth of X_H on S_F		$-\frac{1}{Y_H}$		$\frac{f_{UAP}}{Y_H}$	$-\frac{1-Y_H-f_{UAP}}{2.86\,Y_H}$		1			$\mu_H\eta_{NO3}\frac{K_O}{K_O+S_O}\frac{S_{NO3}}{K_{NO3}+S_{NO3}}\frac{S_F}{K_F+S_F}\frac{S_F}{S_F+S_A}\frac{S_{NH4}}{K_{NH4}+S_{NH4}}\frac{S_{PO4}}{K_{PO4}+S_{PO4}}\frac{S_{ALK}}{K_{ALK}+S_{ALK}}X_H$
Anoxic growth of X_H on S_A			$-\frac{1}{Y_H}$	$\frac{f_{UAP}}{Y_H}$	$-\frac{1-Y_H-f_{UAP}}{2.86\,Y_H}$		1			$\mu_H\eta_{NO3}\frac{K_O}{K_O+S_O}\frac{S_{NO3}}{K_{NO3}+S_{NO3}}\frac{S_A}{K_A+S_A}\frac{S_A}{S_F+S_A}\frac{S_{NH4}}{K_{NH4}+S_{NH4}}\frac{S_{PO4}}{K_{PO4}+S_{PO4}}\frac{S_{ALK}}{K_{ALK}+S_{ALK}}X_H$
Aerobic growth of X_{PAO}	$-\frac{1-Y_H-f_{UAP}}{Y_H}$			$\frac{f_{UAP}}{Y_H}$				1		$\mu_{PAO}\frac{S_O}{K_O+S_O}\frac{S_{PO}}{K_P+S_{PO}}\frac{S_{NH}}{K_{NH}+S_{NH}}\frac{S_{ALK}}{K_{ALK}+S_{ALK}}\frac{X_{PHA}/X_{PAO}}{K_{PHA}+X_{PHA}/X_{PAO}}X_{PAO}$
Anoxic growth of X_{PAO} on NO_3^-				$\frac{f_{UAP}}{Y_H}$	$-\frac{1-Y_H-f_{UAP}}{2.86\,Y_H}$			1		$\eta_{NO3}\mu_{PAO}\frac{K_O}{K_O+S_O}\frac{S_{NO3}}{K_{NO3}+S_{NO3}}\frac{S_{PO}}{K_P+S_{PO}}\frac{S_{NH}}{K_{NH}+S_{NH}}\frac{S_{ALK}}{K_{ALK}+S_{ALK}}\frac{X_{PHA}/X_{PAO}}{K_{PHA}+X_{PHA}/X_{PAO}}X_{PAO}$
Growth of X_{AUT}	$-\frac{4.57-Y_A-f_{UAP}}{Y_A}$			$\frac{f_{UAP}}{Y_H}$	$\frac{1}{Y_A}$				1	$\mu_{AUT}\frac{S_O}{K_{OAUT}+S_O}\frac{S_{NH}}{K_{NHAUT}+S_{NH}}\frac{S_{PO}}{K_{PO}+S_{PO}}\frac{S_{ALK}}{K_{ALK}+S_{ALK}}X_{AUT}$

Modelling SMPs in MBRs (Vanrolleghem *et al.*)

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ASM2dSMP

- Summary: Addition of only:
  - 2 components
  - 6 processes
  - 4 parameters (f_{BAP}, $k_{h,BAP}$, f_{UAP}, $k_{h,UAP}$)
- Parameter values?

Modelling SMPs in MBRs (Vanrolleghem *et al.*)

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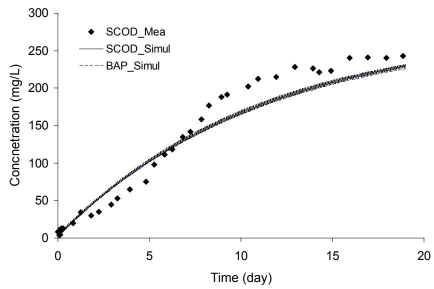
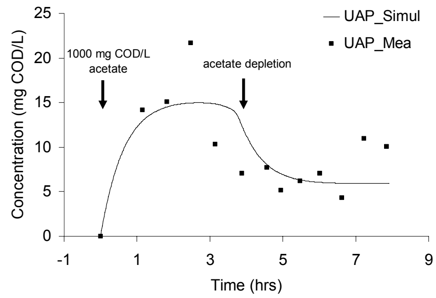
ASM2dSMP Calibration: Parameters





- Calibrated parameters
  - f_{BAP} = 0.0215 (CI=0.0021)
  - $k_{h,BAP}$ = 7.41×10^{-7} 1/d (CI=0.54×10^{-7})
  - f_{UAP} = 0.0963 (CI=0.0387)
  - $k_{h,UAP}$ = 0.0102 1/d (CI=0.0044)

Modelling SMPs in MBRs (Vanrolleghem *et al.*)

ASM2dSMP Calibration: Performance

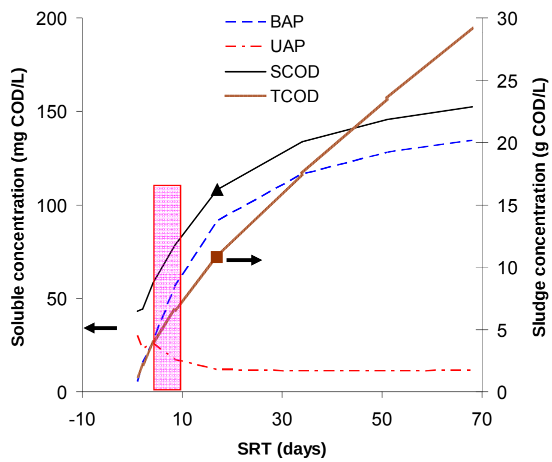
Sample	Item (Unit)	Measured	Simulation (ASM2d)	Simulation (ASM2dSMP)
Waste sludge	Total COD (g COD/L)	10.9	10.83	10.85
Sludge water (reactor)	SCOD (mg COD/L)	87.4	4.5	92.5
Sludge water (mem. loop)	SCOD (mg COD/L)	107.4	5	107.5
Effluent	COD (mg COD/L)	11	5	13.2
	BAP (mg COD/L)			
	UAP (mg COD/L)	n.a.	n.a.	0.9
	NH_4^+-N (mg N/L)	0.18	0.18	0.4
	NO_3^--N (mg N/L)	7.03	8.6	8.6
	PO_4^{3-}-P (mg P/L)	5.63	5.3	5.7

ASM2d ☹ vs. ASM2dSMP ☺

Modelling SMPs in MBRs (Vanrolleghem *et al.*)

ASM2dSMP Application: SRT effect

Fixed HRT and varying SRT/HRT



- SRT → SMP
- Optimal SRT 5-10 days ?

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SMP: Fouling

Specific Resistance to Filtration (SRF)

= *increase in filtration resistance (1/m) per kg of COD present in sludge water delivered to 1 m² of membrane*

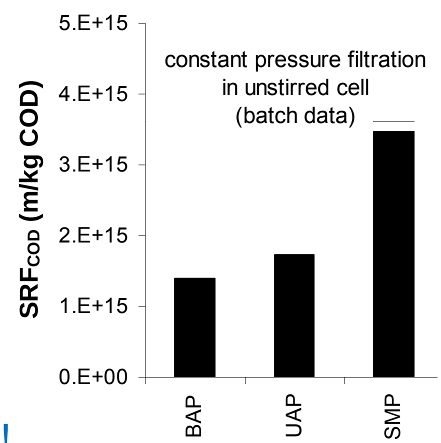
Alternatives:

- *MFI: Modified Fouling Index*
- *SUR: Specific UF Resistance*

SMP: Fouling

SRF measured for different SMPs:

- MBR sludge water
- SMP from BAP test
- SMP from UAP test



Expressed per kg COD !
BAP + UAP also contain low MW components that pass the membrane

Conclusions

- MBR nutrient removal performance can be modelled with classic models, using some adapted parameters
- SMP can be characterized using:
  - LC-OCD and batch tests for UAP and BAP
- SMP production can be modelled
- Different SMPs seem to have different fouling potential