# Modelling the biological nutrient removal of membrane bioreactors

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## Background of this study

- Research conducted in Ghent University, Belgium and UNESCO-IHE, The Netherlands
- Dr. Tao Jiang is currently working for ENVIRON (Shanghai), specialized in industrial wastewater treatment

## Outline

- Introduction to MBR and ASM
- Problem definition and objectives
- Material and methods
- Results and discussion
- Conclusions and perspectives
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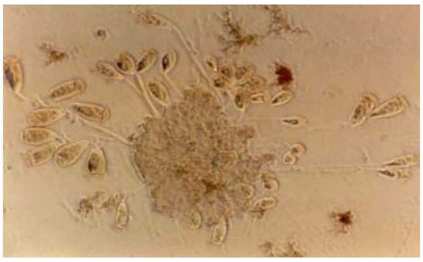
# MBR = activated sludge + membrane

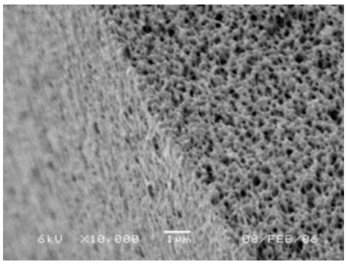


Activated sludge =

bacteria + protozoa + EPS +…

– biodegradable organics (food)

– oxygen



MBR membrane =

porus organic polymers (0.01-0.4 μm)

– exclude larger particles

Biological + physical

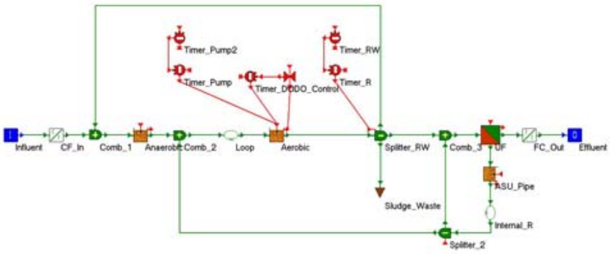


# Activated sludge model 2d (ASM2d)

- Describe biological COD, N and P removal
- Three groups of biomass
  - Ordinary heterotroph: COD removal and denitrification
  - Autotroph: nitrification
  - P-accumulation organisms = special heterotroph (excess uptake of P)
- Simulation software: Biowin, GPS-X, SIMBA, WEST…
- Used in design and optimizing municipal WWTP
- Developed for conventional activated sludge (CAS) process

# Steps of Modelling of WWTP

- Plant survey and data analysis
- Hydraulic model
- Settling model
- Influent characterization and ASM parameter estimation



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## Problem definition

ASM model applicable for BNR in MBRs?



## Objectives

- How to model BNR in MBR system?
- The differences between the ASM-based modelling of MBR and CAS systems?

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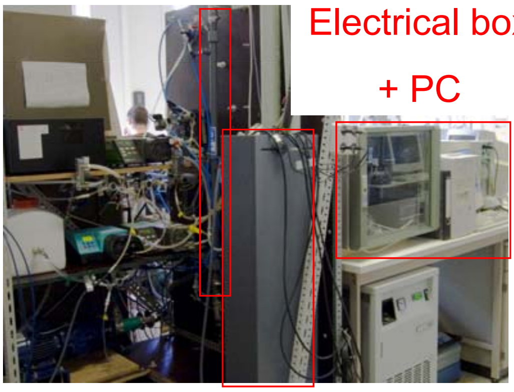
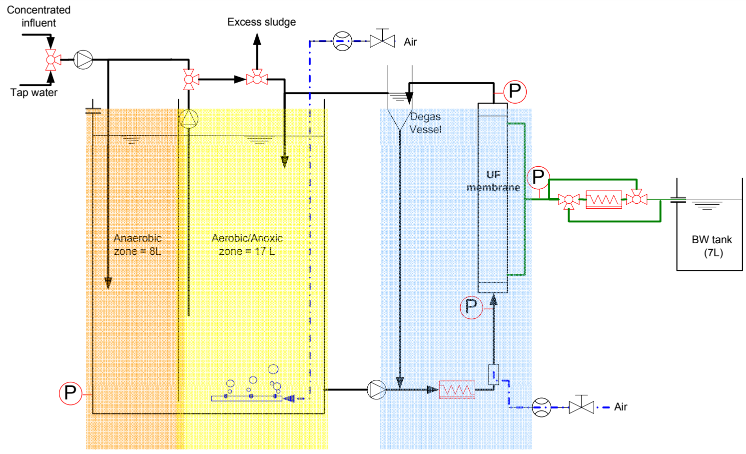
# Lab-scale MBR overview




- Bio. COD, N & P removal
- SRT = 17 d
- HRT = 6.4 hr
- Temperature = 15 °C
- Fully automatic
- Synthetic influent

# MBR configuration

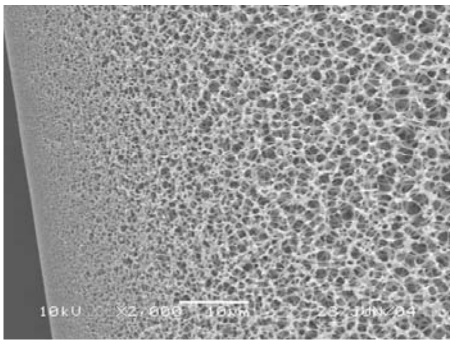



Anaerobic + Aerobic/anoxic + Membrane loop



# MBR membrane

- Ultrafiltration (0.03 µm, 200 kDa)
- Tubular (Φ=5.2 mm, L=1 m, A=0.17 m$^2$)
- PVDF



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## The difference of CAS and MBR modelling

- Plant survey and data analysis
- Hydraulic model
- Settling model
- Influent characterization and ASM parameter estimation

Differenc
e

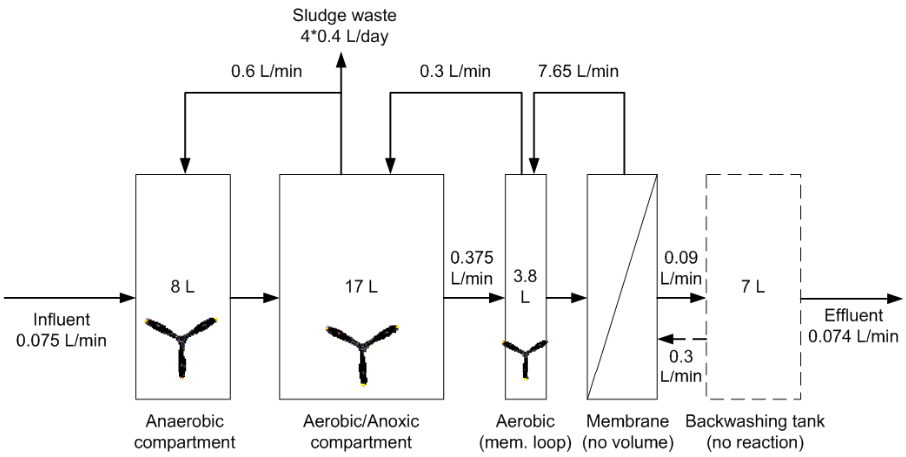
# steady state mass balance of N and P

| Phosphorus mass balance (mg P/day) | | Nitrogen mass balance (mg N/day) | |
|---|---|---|---|
| TP in influent | | | 6,774 |
| TP in effluent | | | 1,083 |
| TP in sludge wastage | 727 | ...e waste sludge | 1,286 |
| | | Nitrate denitrified | 4,265 |
| loss of TP | 0.42% | loss of TN | 2.05% |

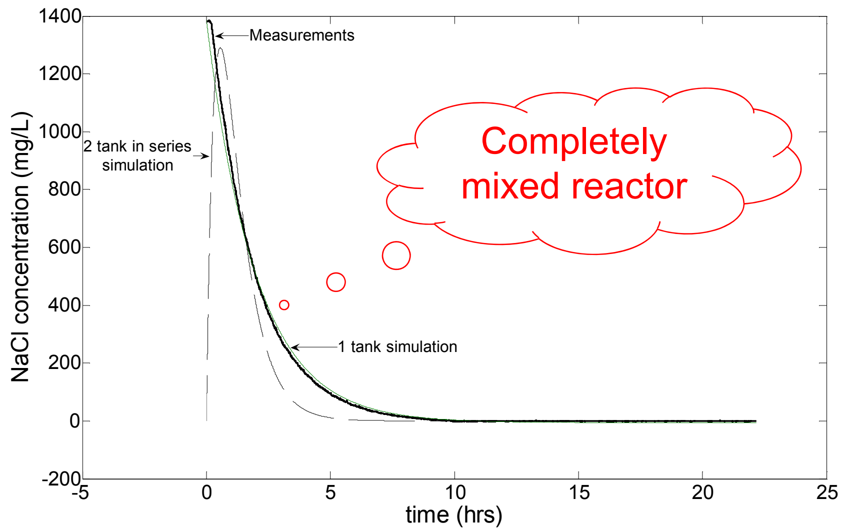
Good data quality



# MBR hydraulic model



# Hydraulic model - Tracer test






# Membrane model - retention

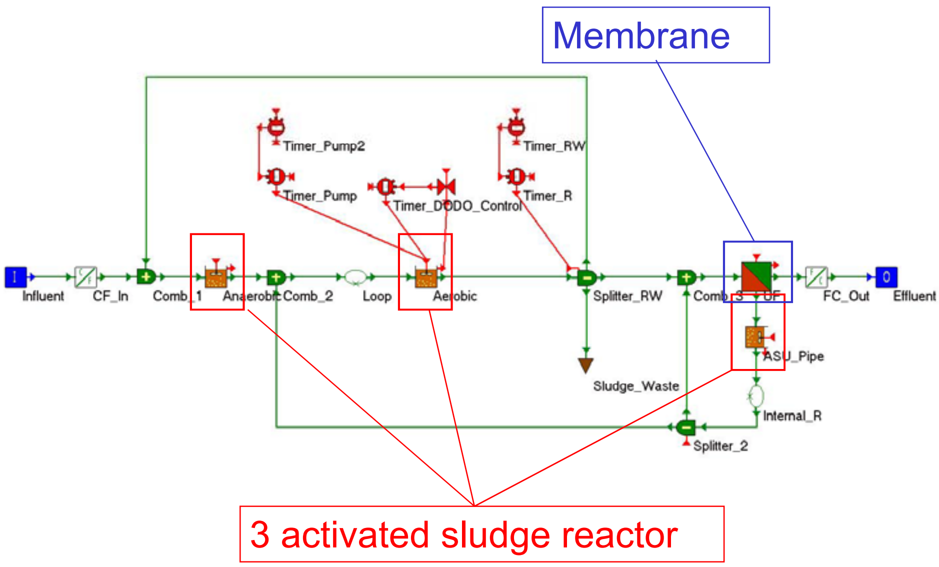
- Complete retention of particulates (> 0.45 μm)
- Retention of soluble COD (SCOD < 0.45 μm)
  - SCOD in membrane feed = 107 mg/L, BOD =1.7 mg/L
  - SCOD in membrane permeate = 11 mg/L
  - High retention percentage of SCOD (90%)
  - Significant amount of SCOD is non-biodegradable
  - non-biodegradable SCOD should be treated as $X_I$

## Membrane model – membrane cleaning

- Membrane backwashing and relaxation reverse or discontinue the flow
- Membrane cleaning impact was evaluated by two simulations:
  - A complete membrane model describing the periodical backwashing/relaxation = Simulation 1
  - A simple membrane model that normalizes the discontinuity = Simulation 2



## MBR model in WEST



## Comparison of measurement and simulation

| Sample (sampling location) | Unit | Values | | | |
|---|---|---|---|---|---|
| | | 4-month avg. | s.d. | Simul_1 | Simul_2 |
| sludge wastage (from aerobic/anoxic compartment) | COD (g/L) | 10.9 | 0.65 | 10.8 | 10.9 |
| Sludge water (sludge wastage < 0.45µm) | COD (mg/L) | 87.4 | 22.7 | 4.5 | 4.1 |
| Effluent (from permeate) | COD (mg/L) | 11.0 (97.[illegible]%) | 3.1 | 5.0 | 4.4 |
| [illegible] | [illegible] | 10.2 (83.7%) | 2.8 | 8.8 | 8.0 |
| [illegible] | [illegible] | 0.18 | 0.42 | 0.18 | 0.20 |
| [illegible] | [illegible] | 7.0 | 1.7 | 8.6 | 7.8 |
| [illegible] | [illegible] | 5.8 ([illegible]3%) | 2.2 | 5.4 | 5.7 |

Underestimate due to

Simu_1(complete) = simu_2(simple)



## Influent characterization - STOWA

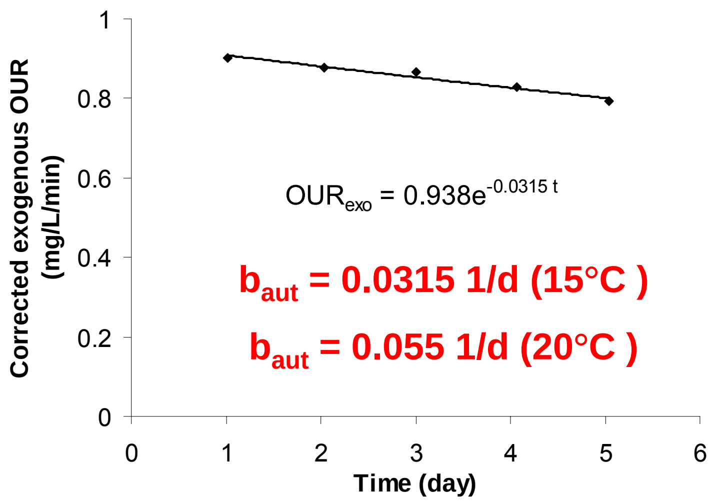
| COD fraction | | Nitrogen fraction | | Phosphorus fraction | |
|---|---|---|---|---|---|
| $S_I$ (mg/L) | 4 | $S_{NH}$ (mg/L) | 46.1 | $S_{PO4}$ (mg/L) | 11.1 |
| $S_A$ (mg/L) | 41.2 | $S_{NO3}$ (mg/L) | 2.94 | $i_{P,SI}$ | 0 |
| $S_F$ (mg/L) | 113 | $i_{N,SI}$ | 0.01 | $i_{P,SF}$ | 0 |
| $X_I$ (mg/L) | 18 | $i_{N,SF}$ | 0.03 | $i_{P,XI}$ | 0.01 |
| $X_S$ (mg/L) | 281 | $i_{N,XI}$ | 0.02 | $i_{P,XS}$ | 0.005 |
| $X_{TSS}$ (mg/L) | 219 | $i_{N,XS}$ | 0.035 | | |
| $S_O$ (mg/L) | 6.5 | | | | |

# ASM2d model calibration

- Traditional experience and process knowledge based approach
  - Decay rate ($X_{aut}$) → batch respirometer (6 d)
  - Decay rate ($X_{het}$) → fit MLSS (4 month average)
  - Nitrification, Denitrification, bio-P
    → trial and error (fit dynamic measurement campaign and 4 month steady state monitoring)



# Exogenous OUR in $b_{aut}$ determination



# Calibrated ASM2d parameter

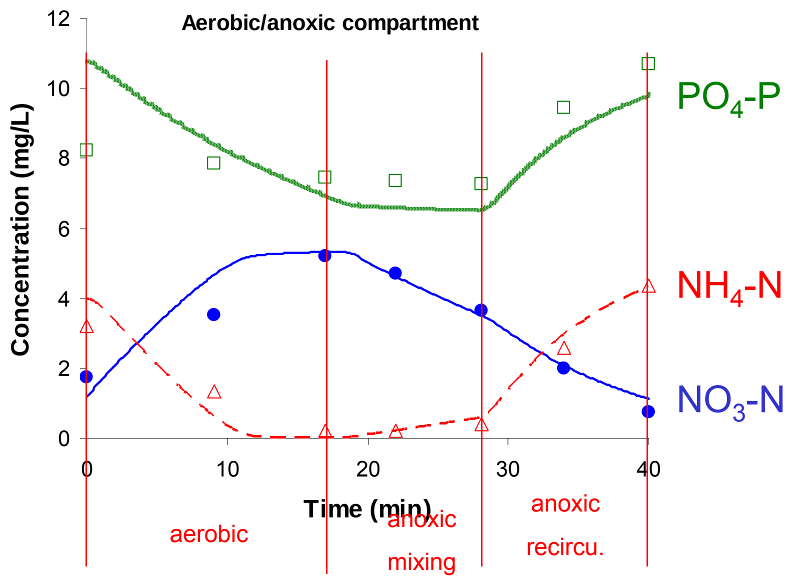
| Parameter name | Symbol | Unit | Default | Calibrated |
|---|---|---|---|---|
| Decay rate of nitrifiers | $b_{aut}$ | 1/d | 0.15 | 0.055 |
| Maximum growth rate of nitrifiers | $\mu_{aut}$ | 1/d | 1 | 0.6 |
| Oxygen half-saturation coefficient of nitrifiers | | | | |
| Ammonium half-saturation coefficient 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 |

Lower decay rate ← alternating aeration

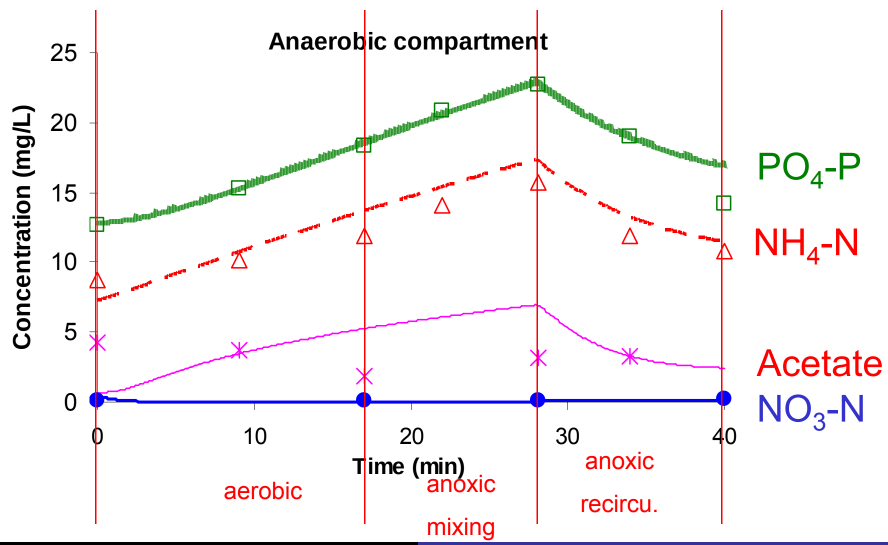
Higher affinity ← smaller flocs



# Fit to measurement campaign



# Fit to measurement campaign






# Modelling MBR vs. CAS

ASM model for CAS can be used in MBRS with cautions:

| | MBR | CAS |
|---|---|---|
| Biomass separation | simple (X retain, S pass) ☺ | complex, dynamic |
| SMP | Accumulation of SMP → <br>• colloidal and refractory, biodegradability independent from size <br>• COD mass balance problem <br>• Overlook SMP, treat as $X_I$ <br>• Inhibit nitrification ☹ | low SMP |
| BW, Relaxation | small improvement if include, normally not necessary ☹ | - |
| Affinity constant | Lower due to smaller flocs ☺ | higher |
| SRT | well defined ☺ | subject to settling |
| Influent $X_I$ | increased sensitivity due to high SRT/HRT ☺ | normal sensitivity |

# Evaluation the BNR performance

- Performance
  - COD removal: 97%
  - TKN removal: 99%
  - TN removal: 84%
  - TP removal: 49%

- Unsatisfied bio-P removal is due to
  - MBR configuration (returning of saturated oxygen flow to aerobic/anoxic compartment)
  - Synthetic influent characteristics
    - COD/TKN=10
    - COD/P=41
    - DO = 6 mg/L
    - $NO_3^-$ -N = 2.9 mg/L



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# Conclusions

- Biological nutrient removal of MBR can be modelled by ASM
- The significant differences between the ASM-based modeling of MBR and CAS systems
  - Accumulation of refractory SMP
  - Membrane cleaning can be normalized to continues flow
  - Lower affinity constant of ASM kinetic parameters



# Perspectives

- ASM model extension with SMP

| Sample (sampling location) | Unit | Values | | | |
|---|---|---|---|---|---|
| | | 4-month avg. | s.d. | Simul_ ASM2d | Simul_ ASM2dSMP |
| sludge wastage (from aerobic/anoxic compartment) | COD (g/L) | 10.9 | 0.65 | 10.8 | 10.9 |
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ASM2dSMP model very well simulated SCOD

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- …