Modelling of Wastewater Treatment Plants

Nevenka Martinello
nevemar@gmail.com
Why do we need WWTP models?

Terminology

Step-wise approach to build a WWTP model

State-of-the-art

What data do we need?

CASE STUDY - WWTP model in Sweden
Why do we need WWTP models?

Rise awareness

Plant design

Process control

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LASA – Environmental Systems Analysis Lab
Step-wise approach to build a WWTP model

**Purpose definition**
- Definition of the WWTP model purpose or the objectives of the model application (learn, design, control)

**Model selection**
- Choice of the models needed to describe the different WWTP units to be considered in the simulation, i.e. selection of the activated sludge model, the sedimentation model, etc.

**Hydraulics determination**
- Determination of the hydraulic models for the WWTP or WWTP tanks

**Flows quality characterization**
- Wastewater and biomass characterization, including biomass sedimentation characteristics

**Calibration**
- Calibration of the activated sludge model parameters

**Simulations**
- Scenario evaluations
Activated Sludge Model 1

- Activated Sludge Model 1, 2, 3 were developed by the task group formed from the International Association on Water Quality (IAWQ, formerly IAWPRC).
- The focus will be on the **Activated Sludge Model 1 (ASM1)**, which is a theoretical mathematical model depicting the biological processes occurring in the activated sludge section of a wastewater treatment plant. It describes carbon oxidation, nitrification and denitrification.
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Activated sludge model
Settling model

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**Activated sludge model**

Settling model

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**Activated Sludge Model 1**

Model processes

- Soluble inert organic matter
- Readily biodegradable substrate
- Heterotrophic bacteria
- Aerobic growth
- Anoxic growth
- Aerobic hydrolysis
- Anoxic hydrolysis
- Soluble biodegradable organic nitrogen
- Ammonification
- Nitrtification
- Nitrate + nitrite nitrogen
- Particulate products from biomass decay
- Death

**Activated Sludge Model 1**

LASA – Environmental Systems Analysis Lab
### Activated Sludge Model 1

<table>
<thead>
<tr>
<th>Component</th>
<th>( i )</th>
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**Observed Conversion Rates:**

\[ r_j = \sum_i v_{ij} \rho_j \]

**Kinetic Parameters:**

- Heterotrophic growth and decay: \( \mu_H, K_S, K_{O,H}, K_{NH}, k_H \)
- Autotrophic growth and decay: \( \mu_A, K_S, K_{O,A}, k_A \)
- Correction factor for anoxic growth of heterotrophs: \( \eta_H \)
- Ammonification: \( k_a \)
- Hydrolysis: \( k_b, k_c \)
- Correction factor for anoxic hydrolysis: \( \mu_a \)
Activated Sludge Model 1

Model Parameters

The stoichiometric parameters are:

- Heterotrophic yield, \( Y_H \)
- Autotrophic yield, \( Y_A \)
- Fraction of biomass yielding particulate products, \( f_P \)
- Mass N/mass COD in biomass, \( i_{XB} \)
- Mass N/mass COD in products from biomass, \( i_{XP} \)

The kinetic parameters are:

- Heterotrophic maximum specific growth rate, \( \mu_H \)
- Heterotrophic decay rate, \( b_H \)
- Half-saturation coefficient for heterotrophs, \( K_S \)
- Oxygen half-saturation coefficient for heterotrophs, \( K_{O2} \)
- Nitrate half-saturation coefficient for denitrifying heterotrophs, \( K_{NO3} \)
- Autotrophic maximum specific growth rate, \( \mu_A \)
- Autotrophic decay rate, \( b_A \)
- Oxygen half-saturation coefficient for autotrophs, \( K_{O2} \)
- Ammonia half-saturation coefficient for autotrophs, \( K_{NH3} \)
- Correction factor for anoxic growth of heterotrophs, \( \eta_g \)
- Ammonification rate, \( k_a \)
- Maximum specific hydrolysis rate, \( k_h \)
- Half-saturation coeff. for hydrolysis of slowly biodegradable substrate, \( K_X \)
- Correction factor for anoxic hydrolysis, \( \eta_h \)

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Activated sludge model
Settling model
LASA – Environmental Systems Analysis Lab
One-dimensional secondary settling tank model

It reproduces the clarification-thickening processes and describes the solids profile throughout the settling column, including the underflow and effluent suspended solids concentrations (Takács, 1991). It is a one-dimensional model, where only processes on the vertical dimension are described, whereas horizontal solids gradients and horizontal velocity contributions are neglected (Vitasovic, 1985). The secondary settler is idealized as a settling cylinder with a constant cross sectional area \( A \).

Main hypotheses:
- The concentration of SS is completely uniform within any horizontal plane within the settler;
- The bottom of the solids-liquid separator represents a physical boundary to separation and the solids flux due to gravitational settling is zero at the bottom;
- There is no significant biological reaction affecting the solids mass concentration within the separator.

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The total flux $J$ consists of the bulk flux $J_b = vX$ and the settling flux $J_s = v_s X$ and becomes:

$$J = J_b + J_s$$

$$J = vX + v_s X$$

where:

- $X$ sludge concentration,
- $v$ vertical bulk velocity,
- $v_s$ particle settling velocity.
One-dimensional secondary settling tank model

The Takács particle settling velocity model

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Maximum practical settling velocity

$V_s$ particle settling velocity

$X_{\text{min}}$, $X_{\text{low}}$, $X_{\text{high}}$
One-dimensional secondary settling tank model

The Takács particle settling velocity model

\[ v_S = \max(0, \min(\sqrt{v'0}, v_0 (e^{-rh(X-X_{\text{min}})} - e^{-rp(X-X_{\text{min}})}))) \]

where

- \( X_{\text{min}} = f_{ns} X_f \)
- Maximum practical settling velocity
- Maximum theoretical Vesilind settling velocity
- Hindered zone settling parameter
- Flocculant zone settling parameter
- Minimum attainable concentration of suspended solids in the effluent
- Non-settleable fraction
- Settler influent TSS concentration

\[ v'0 \quad \text{m d}^{-1} \]
\[ v_0 \quad \text{m d}^{-1} \]
\[ r_h \quad \text{m}^3 (\text{g TSS})^{-1} \]
\[ r_p \quad \text{m}^3 (\text{g TSS})^{-1} \]
\[ X_{\text{min}} \quad \text{g TSS/m}^3 \]
\[ f_{ns} \quad \text{dimensionless} \]
\[ X_f \quad \text{g TSS/m}^3 \]

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Activated sludge model
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LASA – Environmental Systems Analysis Lab
Information required for the model characterization

A relevant step in the implementation of a model is the collection of information from the full-scale WWTP under study

<table>
<thead>
<tr>
<th>Design data</th>
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**What data do we need?**
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Modelling of an activated sludge system in Sweden
High-loaded activated sludge process

- Population equivalent: 500,000
- Flowrate: 4,600 m³/h
- F/M > 0.8 kgBOD (kgTSS d)⁻¹
- Sludge Age: < 2 days
- No nitrification
- TSS reactor = 2600 mgTSS l⁻¹

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It was created and developed mainly by members of the International Water Association (IWA) Task Group, between 1998-2004. It is not linked to any particular simulation platform.

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Information required for the model characterization

A relevant step in the implementation of a model is the collection of information from the full-scale WWTP under study.

**Source of information**

- Executive project
- Data available from on-line sensors and flowmeters
- Measuring campaign
- Respirometry test
- Settling column test

**Design data**
- Reactor volumes, maximum pumpflow rates and aeration capacities.

**Operational data**
- Flow rates, as averages or dynamic trajectories, of influent, effluent, recycle and waste sludge flows.
- pH, aeration (flow rates, valve openings, etc.) and temperatures.

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**Reaction kinetics**
- e.g. growth and decay rates.

**Settler characterization**
- Sedimentation tests for the determination of the settler model parameters.

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**Case study**

**LASA – Environmental Systems Analysis Lab**
A measuring campaign was necessary in order to perform a dynamic simulation of the treatment process, since it requires the knowledge of the diurnal variation of the influent and effluent wastewater quality.

A total of 48 samples, 24 for the influent and 24 for the effluent, were collected and then analyzed for standard pollutants:

- COD (filtered and non-filtered);
- BOD (filtered and non-filtered);
- TSS, Total Suspended Solids;
- VSS, Volatile Suspended Solids;
- NH4-N, ammonium;
- NO2-N + NO3-N, sum of nitrate and nitrite;
- Total nitrogen.
Data collected from experimental work

**Measuring Campaign**

**Influent quality trajectories**

**COD**

- Non-Filtered
- Filtered

**BOD**

- Non-Filtered
- Filtered

**TSS and VSS**

**NH₄-N**

**NO₃-N**

**N tot**

**Alkalinity**

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It is a tool that measures and interprets the rate at which biomass consumes dissolved oxygen. It offers the possibility of indirectly estimating three kinetic parameters of the heterotrophic metabolism required from the Activated Sludge Model 1: i) the maximum specific growth rate, $\mu_{max}$; ii) the decay rate coefficient, $b_h$; and iii) the half-saturation coefficient, $K_s$.

The values of these parameters are not found directly in the test results; therefore, a mathematical sub-model was created for reproducing the process of the test performed. From the calibration of this sub-model, some possible sets of values for the three parameters were obtained. These were then inserted in the full-scale model and further calibrated.
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**Oxygen concentration**

Data collected from experimental work

Respirometry test

Acetate addition

mg O₂/l

hours
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Data collected from experimental work
Respirometry test

**Oxygen concentration**

mg O₂/l

Acetate addition

**Oxygen Uptake Rate**

mg O₂/l/h

Acetate addition
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Data collected from experimental work
Respirometry test

Sub-model calibration

Dissolved oxygen

Oxygen Uptake rate

![Graph showing dissolved oxygen levels over time (t [min])](image)

![Graph showing oxygen uptake rate (OUR) over time (t [min])](image)

- **model output**
- **experimental measurements**
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Data collected from experimental work
Settling Column test

Sludge blanket level

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**Settling Column test**

**Sludge blanket level**

**Zone Settling Velocity**

\[ V_s = v_o \exp(\alpha X) \]

\[ y = -1.1269x + 1.5361 \]
Calibration

Comparison between measurements and model outputs

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LASA – Environmental Systems Analysis Lab
Calibration

Comparison between measurements and model outputs

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COD
BOD
TSS

NH₄-N
NO₃-N
N tot
Thank you for your attention!

ANY QUESTIONS?