Dynamic Optimisation of the Aeration in a Small-Size Alternating Activated Sludge Process

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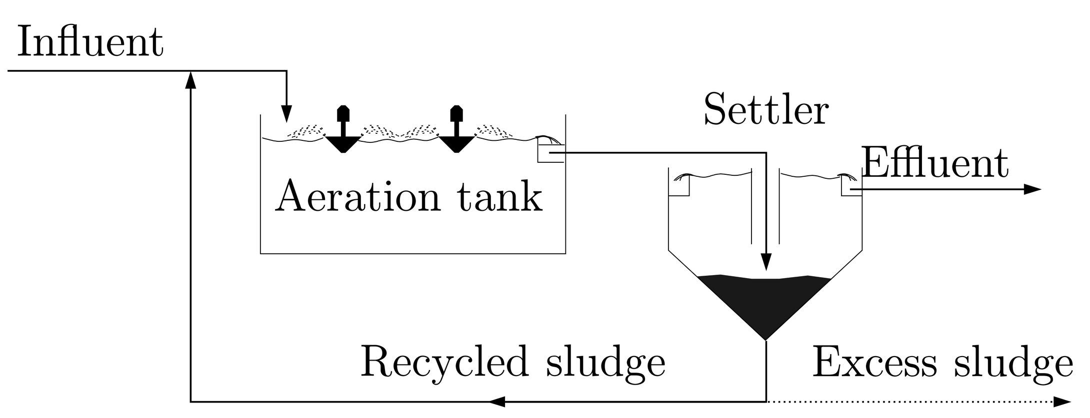
Objectives

- Nitrogen removal in single basin wastewater treatment plant.
- Solution method: dynamic optimisation.
- Determination of the optimal aeration policy (duration of the aeration and non-aeration sequences) which allows to minimise the energy consumption by the aeration system.
- Formulation of simple feedback rules.

Wastewater Treatment Plant Description

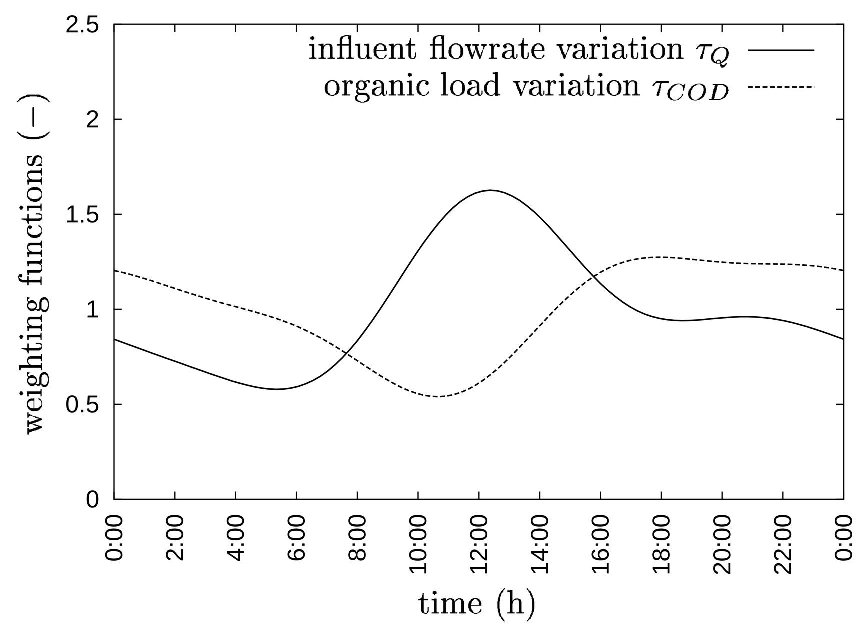
Process



Parameters

- Aeration volume $V^{\mathrm{br}} = 2,050\,\mathrm{m}^3$
- Mechanical surface aerators (turbines) $\mathcal{P} = 30\,\mathrm{kW}$, $k_La = 4.5\,\mathrm{h}^{-1}$
- Recycled sludge flowrate $Q^{\mathrm{rs}} = 7,600\,\mathrm{m}^3/\mathrm{day}$
- Excess sludge flowrate $Q^{\mathrm{w}} = 75\,\mathrm{m}^3/\mathrm{day}$
- Influent: $Q^{\mathrm{in}} = 3050\,\mathrm{m}^3/\mathrm{day}$, $\mathrm{COD}^{\mathrm{in}} = 343\,\mathrm{mg/L}$, $\mathrm{TN}^{\mathrm{in}} = 33\,\mathrm{mg/L}$

Influent Daily Variations



Model

Based on Activated Sludge Model No.1 (ASM 1). Consists of 11 state variables $(S_{\mathrm{I}}\ S_{\mathrm{S}}\ X_{\mathrm{I}}\ X_{\mathrm{S}}\ X_{\mathrm{B,H}}\ X_{\mathrm{B,A}}\ S_{\mathrm{NO}}\ S_{\mathrm{NH}}\ S_{\mathrm{ND}}\ X_{\mathrm{ND}}\ S_{\mathrm{O}})^T$ and 20 parameters. The complete set of equations, parameters values, and influent conditions can be found on the European COST action 624 website http://www.ensic.u-nancy.fr/COSTWWTP.

Optimisation Problem

Variables

Manipulated

- Power to the turbines u_1: on (1) / off (0)
- Aeration cycle: period of aeration followed by a period of non-aeration. The sequence of aeration/non-aeration times is denoted by u_2
- Number of aeration cycles per day N_c
- Initial conditions for the optimal stationary regime $\boldsymbol{x}_0 = \boldsymbol{p}$

Controlled

- chemical oxygen demand (COD),
- biological oxygen demand (BOD),
- suspended solids (SS),
- total nitrogen ($\mathrm{TN} = S_{\mathrm{NO}} + S_{\mathrm{NH}} + S_{\mathrm{ND}}$).

Optimisation

Cost

Minimise aeration time over the period of one day

$$\min_{u_2} J = \frac{\sum_{j=1}^{N_c} u_2(\tau = \frac{2j-1}{2N_c})}{T}$$

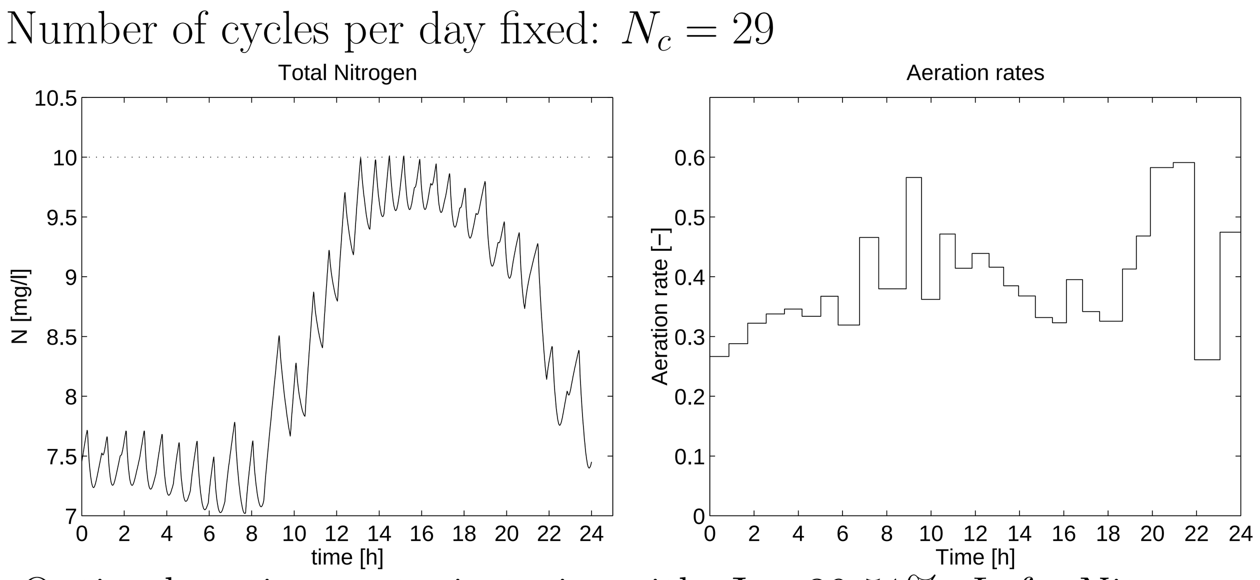
Constraints

$$\begin{aligned}
\mathrm{COD}^{\max} &\le 125\,\mathrm{mg/L} && \text{Maximum effluent constraint on COD}\\
\mathrm{BOD}^{\max} &\le 25\,\mathrm{mg/L} && \text{Maximum effluent constraint on BOD}\\
\mathrm{SS}^{\max} &\le 35\,\mathrm{mg/L} && \text{Maximum effluent constraint on SS}\\
\mathrm{TN}^{\max} &\le 10\,\mathrm{mg/L} && \text{Maximum effluent constraint on total nitrogen}\\
u_2(j) &\in [15, 120]\,\mathrm{min}, \quad j = 1, 2N_c && \text{Constraints on aeration times}\\
T &= \sum_{j=1}^{2N_c} u_2(j) && \text{Optimisation over one day}\\
\|\boldsymbol{p} - \boldsymbol{x}(T)\| &< \varepsilon && \text{Periodic stationary regime}
\end{aligned}$$

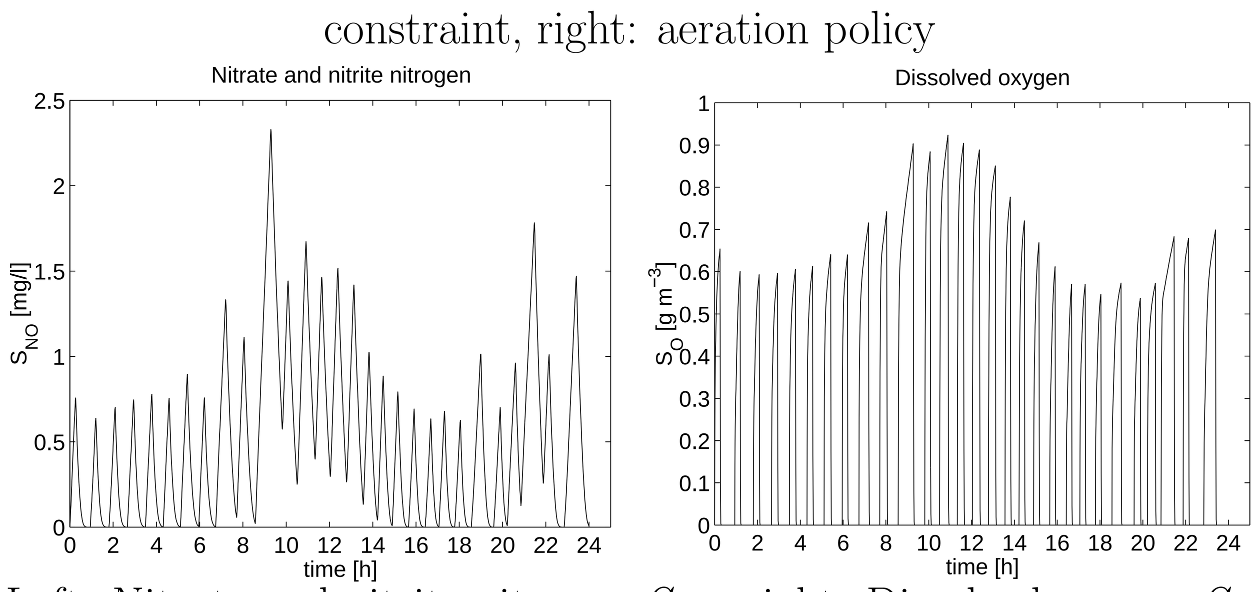
Simulation Results

Optimal Control

Number of cycles per day fixed: $N_c = 29$



Optimal stationary trajectories with $J = 39.51\%$. Left: Nitrogen constraint, right: aeration policy

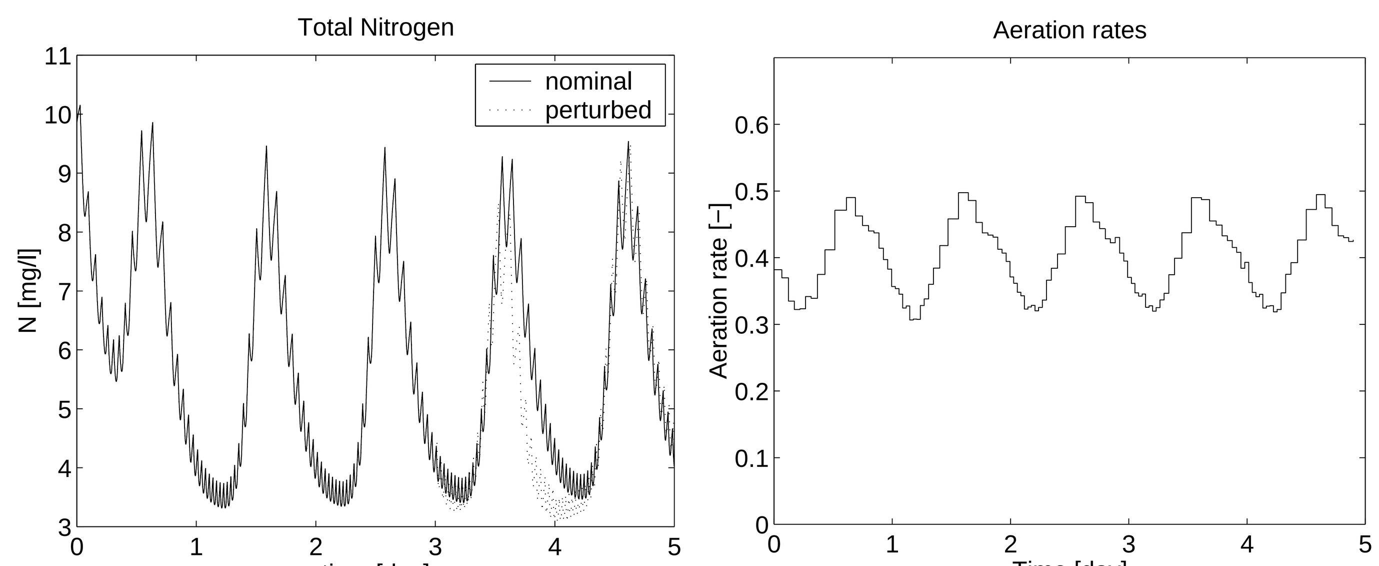


Left: Nitrate and nitrite nitrogen S_{NO}, right: Dissolved oxygen S_{O}

Simple Feedback Rules

Based on optimal nitrate and nitrite nitrogen, S_{NO} and dissolved oxygen, S_{O}, the following feedback rules are proposed

1. Start aeration when S_{NO} decreases sufficiently close to zero,
2. Stop aeration when S_{O} reaches a certain value.



Rule based control over several days. Left: Nominal and perturbed nitrogen constraint, right: nominal aeration policy. Pertubed conditions: 3rd day rainy with 100% increase of influent flowrate and 50% decrease of influent concentrations.

Results: in the long run, TN constraint only very slightly violated with average aeration rate close to optimal.

Conclusions

- Optimisation task defined and solved using the dynamic optimisation solver DYNO (http://www.kirp.chtf.stuba.sk/∼fikar)
- Initial states considered as optimised parameters to obtain periodic steady state.
- Very satisfactory results with rule based feedback control
- Significant reduction of the total aeration time
- Results can indicate the relation between the actual and optimum operation and whether there is a room for improvement that will justify additional investments due to necessary sensors needed for state estimation.
- Stationary profile can be used as a setpoint at the existing plant or the simple rules observed here can be used to enhance the existing operating policies.

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